Peer Learning in a Digital Farmer-to-Farmer Network: Effects on Technology Adoption and Self-Efficacy Beliefs

Violet Lasdun, Aurelie P. Harou, Chris Magomba, and David Guerena

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Violet Lasdun[1], Aurélie P. Harou[2], Chris Magomba[3], David Guerena[4]

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JEL : Q1, Q2, O1, O3

Abstract

Information constraints rank high among barriers to agricultural technology adoption among small-scale farmers, particularly for complex bundles of complementary practices involved in soil fertility management. These techniques involve many components and various strategies for successful implementation, and farmers may face internal constraints to adoption even when external constraints are removed. Information communication technologies (ICTs) are emerging to extend the reach of agricultural training, with potential to deliver information through mobile and smartphones at little or no cost to farmers. The problem remains that beneficial practices are varied and context-specific, requiring a high level of engagement with new information that is difficult to facilitate through ICTs. We develop a low-cost digital extension platform, ShambaChat, to facilitate peer learning through SMS communication on basic feature phones, and use a randomized control trial to evaluate the ability of this ICT to generate self-efficacy gains and promote adoption of beneficial soil fertility management practices among smallholders in Morogoro, Tanzania. We measure a positive impact of treatment on adoption and self-efficacy beliefs when farmers engage with each other through the tool, but find that participants lose interest

[1] violet.lasdun@mail.mcgill.ca, Agricultural Economics, McGill University
[2] aurelie.harou@mcgill.ca, Agricultural Economics, McGill University; corresponding author
[3] Chris_magomba@sua.ac.tz Agricultural Economics, Sokoine University of Agriculture
[4] D.GUERENA@cgiar.org, Alliance Bioversity, CIAT

and do not maintain activity after the first round of treatment. The topic most frequently discussed on the platform was maize-legume intercropping, for which we measure a 14.5% increase in adoption among treated households over and above control households who received the same information without access to the chat groups, and an associated increase in task-specific perceived self-efficacy in the domain of intercropping.

1. Introduction

Despite major gains in agricultural productivity and welfare across much of the developing world, many economies of sub-Saharan Africa (SSA) continue to lag behind in terms of output and food security (Sanchez, 2002). With 70 – 80% of the population employed in agriculture, this sector holds the key to broad-based economic development through accessible productivity gains that increase agricultural yields and incomes for smallholder farmers (Conceição et al., 2016). The success of Green Revolution advances in spurring poverty reductions through increased agricultural productivity across Asia and South America highlights the importance of making effective technologies accessible and coherent to small-scale farmers.

However, use of modern inputs remains strikingly low among smallholders in SSA, with numerous demand and supply-side factors affecting adoption. Moreover, inorganic fertilizer application may not be profitable when soil organic matter (SOM) is low, as is common in much of SSA (Marenya and Barrett, 2009), and fertilizer use in isolation does not build long-term soil fertility (Lal, 2020). Multidimensional approaches like integrated soil fertility management (ISFM), conservation agriculture (CA), and regenerative agriculture (RA), which involve adoption of a set of best-management practices and rely on efficient allocation of on-farm resources show strong potential for enhancing smallholder yields and conserving global soil resources.

Complex bundles of complementary practices can be challenging to introduce, and adoption depends on farmers engaging deeply with information presented in a way that feels relevant and actionable. Moreover, heterogeneity of agro-ecosystems and available on-farm resources means that best-management practices are varied and context-dependent, and the demonstrated success of a technique on one farm may not convince other farmers to adopt. A farmer may understand information presented to her about a new technology with theoretically high returns, but this can fail to spur adoption if she does not believe herself capable of bringing about the same outcomes on her own land, either due to internal constraints such as low self-efficacy beliefs, or because the advice is not tailored to her specific agro-ecological context. Extension campaigns that initiate dialogue between farmers in existing or newly established social networks make new information more accessible by situating it in the experience of a relatable peer and providing concrete evidence of yield and profit outcomes. Farmer-to-farmer extension (F2FE) exploits this networking effect, and there is substantial evidence that learning from peers can promote technology adoption under the right conditions (BenYishay and Mobarak, 2018; Conley and Udry, 2010; Davis et al., 2012; Fisher et al., 2018; Foster and Rosenzweig, 1995; Hellin and Dixon, 2018; Nakano et al., 2018).

However, the conditions under which F2FE leads to adoption and the extent to which peer learning happens through social networks are not fully understood. Some studies suggest, for example, that farmers lack proper incentives to share information with peers (BenYishay and Mobarak, 2018; Kondylis et al., 2017), do not convey precise or detailed information that is actionable by others (Maertens and Barrett, 2012), or fall into a free-rider problem allowing others in their network to bear the cost of experimentation (Bandiera and Rasul, 2006). In recent years, information communication technologies (ICTs) have greatly expanded the accessibility and cost-effectiveness of agricultural extension, and the social-networking capacity associated with ICTs makes digital F2FE an alluring prospect. While ICTs overcome many of the logistical and cost barriers associated with in-person extension, there exists little empirical research into whether users of a digital extension network engage with information in a way that leads to adoption.

In this paper, we ask whether the dynamics of farmer-to-farmer extension (F2FE) can be meaningfully preserved in a digital space, using a low-cost and accessible ICT for non-smart phones (hereafter *feature phones*). This study is among the first to quantify the impact of a digital extension network on adoption, and the first we know of to explicitly measure the impact of peer-learning in a digital space on farmers' self-efficacy beliefs surrounding their adoption capabilities. To study digital F2FE, we develop and test a simple tool, ShambaChat, for facilitating farmer engagement with complex agricultural information delivered by SMS. Through ShambaChat, smallholders are connected in chat groups with others in their region who are growing the same crop and share similar soil nutrient deficiencies. Participants receive scientifically validated information from agronomists, which they are able to discuss by text with the other farmers in their chat groups. We conduct a randomized control trial (RCT) in 47 villages in Morogoro, Tanzania to evaluate the group chat feature of ShambaChat. All households in the study receive the same extension information by SMS, while treated participants are additionally placed in a 5-person chat group and encouraged to chat with each other by text about the extension information and related topics. This experimental design allows us to isolate the effect of the digital networking feature from that of a more traditional SMS extension delivery.

The primary objective of the study is to shed light on the belief-updating process that occurs when farmers gain virtual exposure to role models with more – or simply different – experience with a given technology, and are given the opportunity to grapple with and troubleshoot new information together with a network of peers. Our first question is whether participation in a chat group increases adoption and/or knowledge of the targeted practices relative to farmers who receive the same information through one-way SMS delivery only. We then explore the mechanisms through which peer learning might influence the adoption decision by looking at behavioral outcomes of chat group participation. We focus on perceived-self-efficacy (PSE), or the belief in one's capacity to perform tasks successfully in a specific domain, as a potential mechanism through which peer learning might lead to adoption of new practices. If the group chats give farmers a sense that their peers are able to successfully implement certain practices, this may translate into an increase in PSE, which could in turn contribute to the decision to adopt. Even if no direct evidence of adoption outcomes is available through the group chats, general interest or enthusiasm around adopting new practices might lead to increased PSE if members feel empowered about their own capabilities by the confidence of their peers.

Quantifying the treatment effect of digital networking tools is particularly challenging because more active users may be different from the general population along unobservable underlying characteristics – for example, farmers who engage with the information presented through ShambaChat may be more innovative, or have stronger interest in adopting new practices relative to farmers who are less inclined to engage, leading to an overestimation of the treatment effect on adoption. To mitigate this effect, we use a randomized control trial (RCT) design to estimate the intent to treat (ITT) effect, using first-differences estimation to compare outcomes between households randomly allocated to treatment and control. The conservative estimates produced by the ITT analysis indicate a significant effect on adoption of legume intercropping practices which were the focus of the first month of extension, during which the chat groups were most active. Treated households were 14.5% more likely to intercrop maize with a legume relative to households in the control group, and 8% more likely to identify intercropping by name as a practice they employ. Moreover, we measure a significant increase in self-efficacy beliefs regarding capability of performing intercropping tasks among treated households, with no comparable increase observed in the control group.

This study is situated within a well-developed body of literature on social learning processes among farmers which seeks to understand how farmer-to-farmer knowledge sharing and observation of peers promotes adoption of beneficial agriculture practices (for example, Abay et al., 2017; Conley and Udry (2010); Kondylis et al. (2017); Maertens et al. (2020); Malacarne 2018; 2019; McGinty et al., 2008; Nourani (2019); Taffesse and Tadesse, 2017; Ung et al., 2016). Taken together, this literature suggests a causal pathway wherein farmers observe the yield-effects associated with new practices taken up by early-adopting peers, and then form beliefs about their own likely adoption outcomes and eventual adoption decision. We contribute to this literature by proposing a possible link between peer learning and perceived self-efficacy (PSE) beliefs via a Bayesian updating process in which the presence of a peer network within an extension course decreases the noise associated with an information signal by raising individual farmers' belief in their own capacity to successfully act on the information received, thus encouraging adoption if the signal is positive. We investigate this process empirically by measuring the change in PSE associated with participation in a farmer-to-farmer group chat, and corresponding changes in adoption.

The study can also be placed within the literature on ICTs for agricultural extension. SMS delivery of extension information is an established practice, but evidence of its effectiveness is limited and results are mixed (Aker et al., 2016; Baumüller, 2018, Nakasone et al., 2013; 2014). Existing evaluations look primarily at one-way SMS extension programs that deliver agricultural advice such as reminders about timing of field tasks (e.g., Larochelle et al., 2015), or market information services (MIS) that provide price information (e.g., Fafchamps and Minton, 2012). The subset of the literature on ICTs to which we hope to contribute evaluates projects that engage participants in cognitive processes which promote learning and memory of new information (eg Tjernström et al., 2021; Guilivi et al., 2022). ICTs that incorporate farmer-to-farmer communication functionality exist, but are predominantly internet-based and require a smartphone or computer to access. A notable exception is WeFarm, an SMS-based platform that allows farmers to connect with each other, and with agronomic specialists, and access and share knowledge from a basic feature phone. However, as of yet there are no rigorous evaluations of the impacts of WeFarm on knowledge or adoption of beneficial agriculture practices (Omolo and Kumeh, 2020). Our study is the first we know of that uses an experimental design to evaluate the impact of a digital farmer-to-farmer extension platform.

Finally, although we do not explicitly analyze the conditions under which farmers are able and willing to use an ICT, our assessment of the ShambaChat user experience sheds light on some of the potential limitations of ICTs for facilitating engagement with extension information. We set the stage for further research to iterate on the concept of a digital F2FE platform and ask what kinds of changes to the structure, technology, or presentation of information can be made so that farmers can benefit from innovative social learning tools.

2. Theoretical Framework – Bayesian updating in the presence of peers

To understand why the presence of a peer network may enhance the ability of an ICT extension course to promote adoption, we model the learning process in a Bayesian updating framework following Foster and Rosenzweig (1995) and Lybbert et al. (2007). Farmer *i* begins with normally distributed prior beliefs π_{it} about expected output from adoption given at time *t* by:

$$\pi_{it} \sim N(\bar{\pi}_{it}\,,\, \upsilon_{it}^2) \tag{1}$$

Where υ_{it}^2 reflects the certainty with which she holds the belief about her likely outcome. We can define the farmer's certainty as a decreasing function of the variance of her prior probability belief distribution as follows:

$$\psi_{it} = \frac{1}{\upsilon_{it}^2} \tag{2}$$

This has the (realistic) implication that some farmers, perhaps those who already have some experience with adopting or attempting to adopt a certain practice, would be more confident in their beliefs about their likelihood of success. Later we will see that the more confident someone is in their prior belief, the less they will be influenced by new information.

Next, the farmer receives an information signal π_{it}^m from an extension course, comprised of objective information about the value to be expected from adoption, m_{it}, and a noise signal of ε_{it}. ε_i is normally distributed around a mean 0, and its variance depends on a number of factors that influence the extent to which a farmer accepts the accuracy and relevance of the information provided.

$$\pi_{it}^{m} = m_{it} + \varepsilon_{it} \tag{3}$$

Where:

$$\varepsilon_{it} \sim N(0, \sigma_{it}^{2(\varepsilon)}) \tag{4}$$

So:

$$\pi_{it}^{m} \sim N(m_{it}, \sigma_{it}^{2(\varepsilon)}) \tag{5}$$

The main contribution this model makes to a traditional Bayesian learning framework is to look closely at $\sigma_{it}^{2(\varepsilon)}$ to understand how the presence of a network of peers engaged in a course together changes the way individuals process information from the course. We draw on the literature from health psychology (e.g. Bracke and Verhaeghe, 2008; Feltz et al., 2001; Luszczynska et all, 2004) which suggests that the presence of peers has a positive effect on an individuals perceived self-efficacy regarding their own ability to adopt a practice. If peers in the course are observed taking steps to adopt, or share their experiences of successful adoption in the past, the individual may experience an increased sense of self-efficacy on the basis of a vicarious experience of success: "if they can do it, so can I" (Brown et al., 2013). Even if no one in the group has adopted yet, the existence of a network of peers who are engaging with the information and perceived as being interested and open to the idea that this information may be accurate, pertinent, and useful for them can make the information seem more pertinent to the individual learner.

We posit that the presence of a network of peers in an extension course could increase the farmer's perception of the accuracy of the information as it pertains to her, i.e. reduce the noise of the signal. We define the pertinence of the information signal as:

$$\rho_{it}^{m} = \frac{1}{\sigma_{it}^{2(\varepsilon)}} \tag{6}$$

Where $\sigma_{it}^{2(\varepsilon)}$ depends on how capable farmer *i* believes herself to be of implementing the practices as they are presented and bringing about the output suggested by the course. This is the farmer's perceived self-efficacy (PSE), such that the variance of the information signal is an increasing function of the learner's PSE at time *t*:

$$\sigma_{it}^{2(\varepsilon)}(PSE_{it}) \tag{7}$$

Such that:

$$\frac{\partial \sigma_{it}^{2(\varepsilon)}}{\partial PSE_{it}} < 0 \, ; \, \frac{\partial \rho_{it}^{m}}{\partial PSE_{it}} > 0 \tag{8; 9}$$

Other factors affecting the pertinence of the information signal to farmer *i* might include the degree of trust she has in the extension provider, the teaching style (e.g., Is there a live demonstration of the technique? Is the information provided in person or through an ICT? What type of ICT is used and how comfortable is the farmer with this technology?), and the novelty of the information relative to established and accepted practices. In this paper we explicitly consider only the effect of a peer network – see Guilivi et al., 2022 for a similar model of trust and type of ICT.

The mean of the farmer's conditional subjective probability distribution after the course at time *t+1*, is found by taking the weighted average of the prior beliefs and the information signal received through the course:

$$\bar{\pi}_{it+1|m} = \bar{\pi}_{it} \cdot \frac{\sigma_{it}^{2(\varepsilon)}}{\upsilon_{it}^2 + \sigma_{it}^{2(\varepsilon)}} + m_{it} \cdot \frac{\upsilon_{it}^2}{\upsilon_{it}^2 + \sigma_{it}^{2(\varepsilon)}}$$

(10)

We can define $\delta_i = \frac{\upsilon_{it}^2}{\upsilon_{it}^2+\sigma_{it}^{2(\varepsilon)}}$ (11) as the farmer's updating weight, which measures how much weight she ascribes to the information signal from the course, i.e. how much she will update her belief about her own probability of success with adoption after completing the extension course. This structure takes into account the certainty of the farmer's prior beliefs, ψ_{it}, as well as her perceived pertinence of the information signal, ρ_{it}^m, such that:

$$\frac{\partial \delta_{it}}{\partial \rho_{it}^m} > 0$$

(12)

And:

$$\frac{\partial(1-\ \delta_{it})}{\partial\psi_{it}} > 0$$

(13)

Rewriting the conditional subjective probability from equation (8) in terms of δ_i, we have:

$$\bar{\pi}_{it+1|m} = (1-\ \delta_i)\bar{\pi}_{it} +\ \delta_i m_{it}$$

(14)

Which, given (12) and (13), tells us that the farmer's updating process will give more weight to her prior beliefs (i.e. she will be less influenced by the new information) the more certain she is about these beliefs, for example if she already has some experience with the practice. On the other hand, the updating process will give more weight to the new information signal if the farmer's perception of the pertinence of the signal is stronger, which as discussed above depends positively on PSE. In this way, we have shown how the presence of a peer network could increase farmers' engagement with an extension course and lead to higher adoption, presuming the information signal received through the course delivers a higher expectation of success than the farmer's prior beliefs. Given the low initial level of adoption of the practices under discussion in the present study, this assumption is reasonable.

3. Background

3.1 Morogoro Context

We survey farming households across Morogoro Rural, one of six *wilayas*, or districts, in the Morogoro region of Tanzania. Morogoro is the third largest region in Tanzania, occupying 8.2% (72,939 sq. km) of the country's mainland area, and is home to 5.1% of the population (URT, 2012; NBST, 2014). Morogoro shares key demographic features with the rest of the country, making it an appropriate case study from which we are able to draw some implications for a wider population of rural households. 67% (69.8%) of households in Tanzania (Morogoro) are located in rural areas, and 76.9% (73.3%) of rural workers in Tanzania (Morogoro) are principally employed in own-agriculture (NBST, 2014). Rural poverty is high, with 53% (41%) or rural households living below the basic needs poverty line of $1.90 per day in 2011 in Tanzania (Morogoro) (IFPRI and Datawheel, 2017). Maize is the most common crop grown in Morogoro as well as in Tanzania as a whole, accounting for 27% (35%) of total harvested area in Tanzania (Morogoro), and 60% of dietary calories (IFPRI and HarvestChoice, 2017; Mtaki, 2017). Maize yields are low throughout Morogoro, largely due to soil nutrient deficiencies and minimal fertilizer application. Credit constraints limit use of agricultural inputs, with less than one percent of respondent households reporting fertilizer use in 2014 (Harou et al., 2022).

95% of agricultural land in sub-Saharan Africa (SSA) is managed by smallholders in low-input, rainfed cropping systems (Mutuku et al., 2020). Soil nutrient deficiencies are a key constraint on agricultural productivity in SSA (Jama, 2008; Mutuku et al., 2020; Sanchez, 2002; Snapp, 1998), particularly in these smallholder systems which are often located on marginalized or degraded lands (Jayne et al., 2014). Inherently low nutrient availability and high moisture-stress limit soil fertility across much of SSA, while climate change, intensifying industrial agriculture practices, and a rapidly growing population place compounding burdens on the region's soil resources (Jama, 2008; Jayne et al., 2014; Lunn-Rockcliffe et al., 2020; Place et al., 2003). The inorganic fertilizers that spurred the Green Revolution and rapidly increased agricultural production in Asia and South America since the 1960s have largely failed to take hold across Africa. On average, nitrogen fertilizer application in SSA hovers around 9kg N ha^{-1} yr^{-1}, while most staple crops draw at least 60kg N ha^{-1} yr^{-1} from the soil (Jama, 2008, Myaka et al., 2006; Place et al., 2003). The process of intensifying agricultural production to feed a growing population without replenishing nutrients has resulted in 8 million tons of soil nutrient loss annually since 1970, valued at $4 billion USD in losses per year, and left 75% of agricultural soils in SSA significantly depleted (Jama, 2008; Sanchez, 2002; Toennissen et al., 2008). Productivity losses from declining soil fertility have pushed farmers to expand into marginal land and wilderness areas, where cultivation has low returns and costly environmental externalities (Jayne et al., 2014; Toenniessen et al., 2008).

3.2 Best-Practices for Soil Fertility Management

Integrated soil fertility management (ISFM) and regenerative agriculture (RA) practices hinge on intentional management of on-farm resources, providing an avenue to combat soil nutrient deficiencies at little financial cost to farmers (Al-Kaisi and Lal, 2020; Lal, 2020; Montgomery, 2017; Sanginga and Woomer, 2009). Incorporating legumes into cropping systems can replace much or all of the nitrogen consumed by maize and other staple crops through biological nitrogen fixation (BNF), reducing or eliminating the need for inorganic N fertilizer inputs (Adu-Gyamfi et al., 2007; Myaka et al., 2006; Rusinamhodzi et al., 2012). The benefits of legume intercropping extend beyond BNF, providing, for example, a nutritious and marketable food and cash crop that matures during the ‘hunger season’ when many households have depleted their maize stocks (Adu-Gyamfi et al., 2007; Thurow, 2013). Deep-rooted legume varietals also pull water and nutrients from below ground, making them accessible to maize and bolstering the cropping system against drought and erosion (Adu-Gyamfi et al., 2007). Intercropping requires additional labor, but costs are minimal, especially as farmers can save seeds from one year to the next, and returns are high – indeed, Rusinamhodzi et al. (2012) find that intercropped systems generated a rate of return over 300% higher than monocropped maize.

The full benefits of legume integration are seen when nitrogen-rich crop residues are returned to the soil, where they decompose and release their nutrients which can be taken up again in the next cropping cycle. Organic matter decomposition restores nutrients and enhances biological, physical, and chemical properties of soil, particularly if sustained over time (Berazneva and Güereña., 2019; Palm et al., 2001). There is well documented potential for improving yields and soil fertility through the use of on-farm organic materials as fertilizers (e.g., Demelash et al., 2014; Enujeke et al., 2013; Ikeh et al., 2012; Ndambi et al., 2019; Reetsch et al., 2020), but actual impacts and returns depend greatly on the quality, quantity, and management of these resources (Kwena et al., 2017; Ndambi et al., 2019; Place et al., 2003; Probert et al., 1995; Roy and Kashem, 2014). Organic matter is often of low quality, requiring large quantities to make an impact on soil health (Giller et al., 2009; Vanlauwe and Giller, 2006), and while crop residue is often abundant, there are many competing uses which limit the quantity actually allocated to soil fertility management (Berazneva et al., 2015; Kwenya et al., 2017). Furthermore, most benefits of organic matter application become obvious only in the medium or long run, and risk-averse smallholders operating on short time-horizons may choose to allocate scarce resources to uses with more immediate payoffs (Berazneva and Güereña, 2019).

Managing soil fertility through allocation of on-farm resources and labor overcomes many of the financial constraints inherent to adoption of Green Revolution technologies, but may be equally or more prone to information constraints. Smallholders in Malawi, for example, report that lack of information was the key constraint to adopting best-management practices for manure (Ndambi et al., 2019). Ndambi et al. (2019) propose robust extension services that facilitate knowledge sharing among farmers as the best route to overcoming this challenge. Indeed, soil fertility management practices are knowledge-intensive, requiring deep understanding of ecosystem flows and nutrient cycling, and awareness of specific practices that harness these dynamics for crop production (Jama, 2008; Lunn-Rockliffe et al., 2020, Montgomery, 2017, Sanginga et al., 2009). Appropriate practices are derived from the specific agro-ecosystems they seek to improve, looking to locally available resources, climate conditions, native species, and indigenous cropping systems to identify the best methods for bringing about desired soil fertility and yield outcomes in each case or locale (Barrett et al., 2002, Holt-Giménez, 2006; Massy, 2020; Montgomery, 2017). Moreover, best-management practices are varied and context-dependent, and rely on farmers having an understanding of the ecological systems they are managing. For example, given an understanding of organic matter decomposition and carbon cycles, farmers can then iterate on different composting practices to find something well-suited to their particular agroecological conditions such as farm size, available organic material, and climate. Reaching farmers with the tools required for successful experimentation with soil fertility management must go beyond simple broadcasting of information from agronomists, equipping farmers with an understanding of ecological principles and facilitating farmer-led innovation and design of cropping systems that fit farmers' specific goals and constraints (Lunn-Rockliffe et al., 2020).

4. Experimental Design

4.1 Household Selection and Data Collection

523 participating farmers were surveyed at baseline in August and September 2020 from a randomized network of 1050 households across 47 villages in Morogoro Rural. The initial randomization process occurred in 2014, when farming households were selected to participate in an experimental fertilizer recommendation initiative (Harou et al., 2021). The original randomization took place at the village and individual levels, with 47 villages selected out of all villages in Morogoro Rural that were accessible by vehicle and known to grow maize. Data on assets, demographics, food security, and agricultural production were collected from all participating households in 2014, 2016, and 2019. The fertilizer initiative succeeded in increasing input use and maize yields among treatment households in 2016, but with little to no significant remaining effect detected in 2019 (Tamim et al., 2021).

We used cellphone numbers listed in the 2019 surveys to contact households at baseline in 2020, and conducted two 30-minute phone interviews with each household in an effort to be less demanding on respondents in terms of time and attention. We were able to reach 523 households for the first interview segment, and 468 in the second, likely because some farmers had left their villages in early September to prepare fields and lost cellphone coverage. This attrition is not correlated with treatment, nor with any relevant household demographics or outcome variables (see Appendix A). In the interest of maintaining a large sample size, we chose to keep all 523 households in the study, despite lacking baseline values for many relevant outcome variables for the 55 participants missing Part Two.

4.2 The ShambaChat Extension Platform and Usage

To build the ShambaChat extension platform we partnered with Telerivet, a mobile communications platform that manages interactive SMS campaigns for businesses and NGOs internationally. The platform allowed us to broadcast extension messages and discussion prompts from a computer anywhere in the world directly to the cellphones of participating farmers in Morogoro. Additionally, it enabled us to group participants into 5-person chat groups – a novel functionality for feature phones – where they could respond to our extension messages and discuss the content freely over SMS. If a (treated) farmer responded to any message received through ShambaChat, whether from us or another farmer in her group, the message was automatically forwarded to the other members of her chat group, who were able to respond in turn. On feature phones, each message arrived as a separate SMS tagged with the first three letters of the sender's name, or "SUA" for the extension messages broadcast by our team. While a bit clunky, this interface enabled users to follow a conversation, as messages were received in the order they were sent, and the sender was clearly identified. To ensure privacy, all phone numbers were concealed and replaced with the three-letter nametag. Since participants were randomly allocated to chat groups and did not know each other prior to the study, we made an effort to instigate conversation by broadcasting several icebreakers to the groups encouraging members to introduce themselves with their name and village (see Appendix B for a full transcript of these messages). In theory, this technology allows for relatively easy communication between chat group members and facilitates discussion and engagement with the extension content.

4.3 Treatment Arms

The goal of this study is to assess the specific impact of augmenting SMS extension delivery with a group chat feature, and for this reason we chose to broadcast extension messages by SMS to *all* study participants. Limiting our scope to only two treatment arms had the advantage of preserving a larger sample size when comparing outcomes between treatment and control groups, but we forego the ability to assess the impact of the extension platform more holistically relative to no intervention.

The 523 participating households were sorted into treated and control groups, with a subset of the control group consisting of 87 households in 10 randomly selected pure control villages to allow us to understand potential spillover effects – see Section 5.4. In treatment villages, we sorted all households into five-member chat groups, and then randomly assigned each chat group to either treatment or control. To ensure heterogeneity of experience within the chat groups, we included two farmers in each group who had some experience with the agricultural practices we intended to promote. To do this, we used farmer responses at baseline to identify all farmers who planted legumes in 2020 (hereafter, criteria F1) and used a soil conservation practice in 2020 (grass strips, ridges, bench terraces, drainage channels, water catchment, or other) (hereafter, criteria F2). 88 chat groups were formed from the 436 farmers in the remaining 37 treatment villages, with one member each of F1 and F2, along with three randomly selected members. We then allocated the chat groups randomly to treatment or control, with 34 control groups and 54 treatment groups. Chat groups assigned to control were dissolved, as only treated farmers would be participating in these groups during the study, leaving a total of 257 control households (across treatment and control villages) and 266 treated households at baseline.

4.4 SMS Extension Course

Given the prevalence of nitrogen deficient soils in our sample[5] and in SSA more generally, we selected a bundle of regenerative soil fertility management practices that promote soil health through enhanced biological processes and ecosystem dynamics. The selected practices are based on intentional management of on-farm resources, providing an avenue to combat soil nutrient deficiencies at little or no financial cost to farmers (Al-Kaisi and Lal, 2020). These practices substitute knowledge for input intensity, overcoming some of the constraints associated with promoting uptake of agricultural inputs like inorganic fertilizers, while presenting new challenges. High-quality, adaptive extension programs are key to promoting adoption of complex and context-specific technology bundles like regenerative soil fertility management, making this an appropriate topic to address through the ShambaChat platform (Lunn-Rockliffe et al., 2020).

We developed a 3-part course on soil building, focusing on legume-maize intercropping in Part 1, green manure and composting in Part 2, and integration of crop residues in Part 3 – although there was not a strict delineation of topics by course section. Each part of the course lasted one month, during which participants received 3-5 messages per day excluding weekends (see Appendix B). The messages contained information about techniques for implementing the targeted practices, the agronomic benefits of doing so, and scientific principles behind their effectiveness, as well as discussion prompts that led farmers to think more deeply about the information and encouraged them to relate it to their own experience or knowledge of similar practices. The course, including discussion prompts, was delivered by SMS to both treatment and control participants. Treated participants additionally had the ability to discuss this information with other farmers in 5-person chat-groups. To ensure farmers did not bear a cost of participating, we paid for unlimited texting for the duration of the study period for all households, both treatment and control.

[5] Soil testing was performed at each household in 2014 for a previous study, Harou et al. 2022.

4.5 Outcome Variables

We are interested in whether the ShambaChat group chat treatment promotes adoption of beneficial practices, and in understanding the psychological mechanisms through which peer learning can influence behavior.

4.5.1 Adoption Outcomes

We look at seven indicators of adoption to capture any relevant changes in production decisions in response to the treatment. The extension course focused primarily on legume nitrogen fixation and cycling organic nutrients through decomposition of on-farm organic materials, with specific practices falling into these two categories. Although we asked in great detail about adoption of each practice, the number of positive responses to specific items in most cases was too low to analyze efficiently, so we chose to aggregate them into broader practices resulting in four indicators tracking adoption of legume practices, and three tracking adoption of organic materials practices.

Legumes:

i. Intercropping with legumes on main maize plot (MMP) (1): *Intercropping 1* takes a value of one for respondents who select one or more legume from a list of crops in response to the question "*Which of the following crops did you plant alongside maize on your MMP?"* and zero otherwise. Respondents who did not cultivate maize are omitted.

ii. Intercropping with legumes on MMP (2): *Intercropping 2* takes a value of one for respondents who select "*Intercropped maize with legumes"* in response to the question

"*Which of the following practices did you use on you MMP?*", and zero otherwise. Respondents who did not cultivate maize are omitted. This metric is distinct from (i) because some farmers may plant a legume alongside maize without recognizing this practice as intercropping.

iii. Other legume practices: *Other Legume Practices* takes a value of one for farmers who use cover cropping, crop rotation, or relay planting methods with legumes, and select one of these practices in response to the questions "*Which of the following practices did you use on your MMP?*", and zero otherwise. Respondents who did not cultivate maize are omitted.

iv. Legumes on farm: *Legumes on Farm* is equal to one for any farmer who selects a legume from a list of crops grown anywhere on their farm, not limited to the MMP. This variable was not collected at baseline, but we asked for recall data at endline to estimate the level in 2020. This measure includes farmers who did not cultivate maize.

Organic Materials:

i. Organic materials found or produced on farm: *Organic Materials* is equal to one for farmers who find or produce an organic material, including crop residue, manure, leaf litter, or transfer of forest soil anywhere on their farm, and zero otherwise. Due to a lack of foresight when developing the survey, farmers who do not cultivate maize are omitted from this measure.

ii. Making fertilizer from on-farm organic materials: *Made Organic Fertilizer* is equal to one for farmers who find or produce organic materials on their farm and state that they used this material as a fertilizer, either by incorporating it into compost or leaving it to decompose directly on the field, and zero otherwise.

iii. Applying organic fertilizer on the MMP: *Organic Fertilizer - MMP* is equal to one for farmers who applied organic fertilizer on their MMP, and zero otherwise. Respondents who did not cultivate maize are omitted.

4.5.2 Behavioral Outcomes

We measure five psychometric variables in an effort to explain the process by which farmers engage with the group chat functionality of ShambaChat and change their behavior in response to the information received. These outcomes are difficult to measure and in some cases there is no standard method for doing so. For this reason we describe our methods in detail, and the survey modules presented to respondents are included in Appendix B. We construct a knowledge score based on five questions about soil fertility management practices to compare participants' knowledge of the targeted practices before and after the intervention. We also construct three measures of perceived self-efficacy, or an individual's belief about her capabilities in reference to a specific domain of functioning. Finally, we use a game to elicit a subjective probability distribution over adoption outcomes.

i. Knowledge Score (*knowledge*_score): We ask five questions about best-practices surrounding soil fertility management. Four questions specifically address the targeted practices, with a focus on identifying legume crops and applying organic fertilizers. A fifth question about seed spacing, which was not a topic covered in the extension course, is included as a control. The final score is calculated out of 16 possible points.

ii. Generalized PSE (*PSE_general*): PSE is a concept from cognitive social science, popularized by Albert Bandura (1977) as a component of his social learning theory. An individual's PSE is a measure of her beliefs about her own ability to perform tasks or behaviors which are necessary for success in a particular domain. Following Chen et al. (2001), we administer the New General Self-Efficacy (NGSE) scale, loosely adapted to the domain of agriculture. The NGSE scale consists of eight items that measure an individual's confidence in her ability to meet task demands and achieve goals. Each item is rated on a 1-5 point Likert scale, and a score, *PSE_general*, is calculated by taking the average over all items.

iii. Domain-specific PSE (*PSE_outcome_soilfertility; PSE_outcome_profits; PSE_outcome_foodsecurity; PSE_task_furrows; PSE_task_seedspacing; PSE_task_intercropping; PSE_task_manure*): We constructed a module to measure PSE for specific tasks and outcomes within the domain of RA, following the methodology of Schwarzer and Renner (2009) and Bandura (2006). Bandura argues that scales like the NGSE are too general, and fail to capture the domain-specific nature of PSE, even when loosely adapted to a domain as we do in (ii), above. Indeed, while many psychological constructs cut across all domains of functioning, PSE is linked to specific contexts and spheres of action. Despite high correlation across different domains of functioning, an individual's PSE in reference to a certain task may change as she becomes more confident in her capabilities to perform in this domain, for example through learning-by-doing, or exposure to a role model. A domain-specific PSE scale must meet certain criteria for validity (Bandura, 2006), namely:

- Should be phrased in terms of capabilities, not intentions (eg., “I am able to” instead of “I will do it”), and should measure “perceived capability to produce given attainments” (Bandura, 2006).
- Should focus on ability to perform specific tasks.
- The tasks specified in the scale should in fact be the determinants of success in the relevant domain (e.g., proper input use in fact leads to improved yields).
- The scale should reflect gradations of challenge, so that respondents can indicate their perceived level of difficulty associated with performing each task, and/or their confidence in their ability to perform them.
- The scale should elicit respondents’ beliefs about their capabilities as of now, not their expectations about potential capabilities in the future.

We include one module for domain-specific PSE, but elicit two metrics – one that covers PSE over specific outcomes, and one that looks at PSE over specific tasks. Each metric consists of 3 and 4 outcome variables, respectively, listed above

4.6 Attrition

Out of 523 households surveyed at baseline in August 2020 and included in the study, we were able to reach only 410, or 78.4%, at endline in August 2021. This represents an attrition rate of 21.6%, and could result in biased estimates if participants do not drop out of the study at random.

We posit that the high rate of attrition between 2020 and 2021 is largely due to recent changes in Tanzanian laws regarding SIM card registration. A new law went into effect in February 2020, requiring Tanzanians to biometrically register their SIM card. In the months following, many individuals adjusted to the new law, resulting in high turnover of cellphone numbers. Moreover, even without the upheaval of a new law, it is well-documented that in developing countries cellphones and SIM cards are often shared among household members or switched out, so an individuals' phone number tends to change frequently (Aker et al., 2016; Steinfield et al., 2015). Indeed, we find that attrition is not correlated with treatment assignment, as treated and control households attrit at the same (i.e. not statistically different) rates, and that attrition is not correlated with any household demographic or outcome variables. See Appendix A for further discussion.

4.7 Baseline Balance

Despite randomization of households, we verify that all outcome variables and relevant household demographics are balanced at baseline between treatment and control groups, as well as between control households in treatment villages and control households in pure control villages. To conduct these balance tests, we regress baseline levels of outcome and demographic variables on a treatment indicator using OLS with the following specification, with standard errors clustered at the village level:

$$y_i = \alpha_0 + \theta_1 TREAT_i + \varepsilon_i \quad (1)$$

4.7.1 Balance of Treatment and Control Households

We first set the treatment indicator $TREAT_i$ equal to one for treated households and zero for all control households, and run the model specified in equation 1. The results of these regressions are reported in Table 1, where we see the mean and standard deviation in the level of each variable for treatment and control groups, respectively, and the difference in these levels. Any statistically significant difference is indicated with an asterix in Column 5. As we see, there is a significant difference in the baseline levels for knowledge score and other legume practices. The difference in outcome variables is controlled for by the first-differences estimation technique we follow in our main results section, 5.2, and we do not see any imbalance in relevant household characteristics between treatment and control groups. Note that this imbalance does not imply selection bias, which is removed by the random allocation of households to treatment or control.

Table 1: Balance of Treatment and Control Households at Baseline

Baseline 2020 Variable:	**(1) Mean of Control**	**(2) SD of Control**	**(3) Mean of Treated**	**(4) SD of Treated**	**(5) Difference in Means**
Village	23.15	11.59	23.97	11.80	0.812
Age of hh head	45.55	13.74	44.40	12.89	-1.148
Gender of hh head	0.17	0.38	0.14	0.35	-0.031
Education completed by hh head	6.37	1.96	6.35	2.02	-0.023
Dependency ratio	157.56	106.99	156.93	118.33	-0.624
Food insecurity index	2.26	1.89	2.08	1.77	-0.186
Land owned (acres)	6.65	8.25	6.18	7.31	-0.463
Do you own your MMP?	0.90	0.30	0.90	0.30	0.005
Asset Index	0.06	2.19	0.01	2.29	-0.051
Maize yield (kg/acre)	282.69	348.90	288.36	496.12	5.670
Intercrop w legume on MMP (1)	0.18	0.38	0.15	0.36	-0.027
Intercrop w legume on MMP (2)	0.12	0.33	0.10	0.30	-0.025
Other legume practices	0.12	0.33	0.21	0.41	0.085**
Legumes on farm	0.29	0.46	0.35	0.48	0.054
Produced organic materials	0.58	0.50	0.67	0.47	0.090
Made organic fertilizer on-farm	0.28	0.45	0.19	0.40	-0.087
Applied organic fertilizer MMP	0.26	0.44	0.26	0.44	0.001
RA knowledge score	2.64	2.41	3.27	2.33	0.632***

General PSE score (mean)	3.31	0.84	3.32	0.78	0.008
PSE Outcomes: Soil Fertility	3.84	1.25	3.90	1.16	0.067
PSE Outcomes: Profits	3.77	1.25	3.82	1.16	0.048
PSE Outcomes: Food Security	4.02	1.27	4.14	1.15	0.118
PSE Tasks: Furrowed Ridges	2.38	1.21	2.24	1.18	-0.140
PSE Tasks: Seed Spacing	1.19	0.57	1.15	0.42	-0.040
PSE Tasks: Intercropping	1.30	0.77	1.28	0.68	-0.023
PSE Tasks: Poultry Manure	2.04	1.23	1.96	1.13	-0.083
SPD over soil fertility outcomes	305.77	417.20	296.16	444.20	-9.606
SPD over profit outcomes	326.92	440.75	318.44	441.50	-8.482
SPD over food security outcomes	390.26	427.31	384.90	463.57	-5.355

*** p<0.01, ** p<0.05, * p<0.1

4.7.2 Balance of Control Households in Treatment and Control Villages

We also test the balance of outcome and demographic variables between control households in treatment villages, and control households in pure control villages, which will help us account for any potential spillover effects of the treatment in Section 5.4. For this test we set $TREAT_i$ equal to one for control households in treatment villages, and zero for households in control villages. Results, presented in Table 2, show that several variables are indeed unbalanced between the two control groups. These groups were initially balanced at baseline before attrition occurred. We address this imbalance in Section 5.4.

Table 2: Balance of Control Households in Treatment Villages and Pure Control at Baseline

	(1)	**(2)**	**(3)**	**(4)**	**(5)**

Baseline 2020 Variable:	Mean of Pure Control	SD of Pure Control	Mean of Control in Trt Vil	SD of Control in Trt Vil	Difference in Means
Village	24.03	8.14	21.29	11.72	-2.741
Age of hh head	46.53	15.60	45.07	12.77	-1.463
Gender of hh head	0.20	0.41	0.15	0.36	-0.050
Education completed by hh head	6.48	1.74	6.32	2.06	-0.164
Dependency ratio	149.96	95.07	161.27	112.52	11.310
Food insecurity index	2.25	1.86	2.27	1.91	0.020
Land owned (acres)	4.77	3.75	7.56	9.61	2.788**
Do you own your MMP?	0.82	0.39	0.94	0.24	0.115*
Asset Index	-0.06	2.04	0.12	2.26	0.185
Maize yield (kg/acre)	244.45	341.57	302.79	352.78	58.349
Intercrop w legume on MMP (1)	0.22	0.42	0.15	0.36	-0.061
Intercrop w legume on MMP (2)	0.16	0.37	0.10	0.31	-0.054
Other legume practices	0.10	0.30	0.13	0.34	0.036
Legumes on farm	0.16	0.37	0.37	0.48	0.203**
Produced organic materials	0.53	0.50	0.61	0.49	0.079
Made organic fertilizer on-farm	0.48	0.51	0.19	0.39	-0.295*
Applied organic fertilizer MMP	0.31	0.47	0.24	0.43	-0.077
RA knowledge score	2.42	2.28	2.75	2.48	0.335
General PSE score (mean)	3.39	0.84	3.27	0.84	-0.111
PSE Outcomes: Soil Fertility	4.13	1.13	3.68	1.28	-0.450**
PSE Outcomes: Profits	3.95	1.17	3.68	1.29	-0.266
PSE Outcomes: Food Security	4.25	1.13	3.90	1.33	-0.353
PSE Tasks: Furrowed Ridges	2.38	1.24	2.38	1.21	-0.005
PSE Tasks: Seed Spacing	1.03	0.18	1.28	0.68	0.246**
PSE Tasks: Intercropping	1.25	0.68	1.33	0.82	0.080
PSE Tasks: Poultry Manure	2.07	1.21	2.03	1.24	-0.041
SPD over soil fertility outcomes	335.94	412.84	291.03	420.10	-44.907
SPD over profit outcomes	350.78	415.28	315.27	453.76	-35.514
SPD over food security outcomes	417.58	378.64	376.91	449.96	-40.670

*** p<0.01, ** p<0.05, * p<0.1

4.8 Intent to Treat Effects (ITT) and Compliance

Our lack of control over the way in which study participants engaged with the ShambaChat app, coupled with the reality of limited and patchy network coverage in the Morogoro region, resulted in partial or non-compliance with treatment for some households. 40 out of the 410 households interviewed at endline in 2021 reported that they did not receive any extension messages from SUA, likely due to poor cellphone coverage or switching their phone number at some point in the 6 months between the baseline data collection and the start of the messaging campaign. Of these, 17 were treated households and 23 were control. Moreover, many participants in the treatment group did not actively participate in the group chats, so it is difficult to say whether and to what extent they benefited from the treatment. In some cases they may have benefited from reading what others in their chat groups were discussing, but some chat groups had no discussion at all, in which case the experience of these treated participants would have been identical to members of the control group (who were not placed in a chat group but still received extension messages through ShambaChat). To account for this partial and non-compliance, we follow an intent-to-treat (ITT) analysis throughout this study to estimate the coefficients for all participants who were randomly assigned to the treatment group, regardless of whether or to what extent they actually received or engaged with the treatment. This approach may result in an underestimation of the full treatment effect.

We also include a brief analysis of the effect of treatment on the treated (TOT) as a robustness check, in which we define active groups in which at least one farmer participated, and instrument this variable with the randomly allocated treatment variable to reduce the potential bias resulting from unobserved correlation between more active farmers and higher proclivity to adopt. Although we account for some of this bias by using an instrumental variable (IV) framework, we rely mostly on the ITT analysis to provide the most conservative and unbiased estimates. The IV results are consistent with the ITT analysis across all outcome variables, and as we would expect, the significant outcome variables have higher coefficients, indicating that the ITT analysis may underestimate the full effect of treatment for farmers in active chat groups.

5. Empirical Strategies and Results

5.1 Summary Statistics

5.1.1 Description of Household Characteristics at Baseline

The 410 households participating in our study (after attrition) are located in Morogoro Rural, a district in the Morogoro region of Tanzania, across 47 in villages which predominantly grow maize. 84% of households in our sample cultivated maize in 2020, mostly for household consumption. The average household-head is male and 45 years old. 93% of household heads have completed some education, but only 7% have completed any years beyond primary school (7 years in Tanzania). 15% of households are female-headed. 90% of households own at least one acre of land, with mean land holdings in 2020 around 6 acres, although this is skewed by a few large landholders. 92% of households own their home, which are typically constructed of stone or mud bricks with corrugated metal roofs, and 90% of maize cultivators own their own maize plot. 9% of households have electricity, and 3% have an indoor water supply. Average maize yields in 2020 were 286 kg/acre, which is low compared to 514.2kg/acre average yields recorded for Morogoro between 1994 and 2001 (Harou et al., 2021; Paavola, 2008), although this number likely suffers from reporting error.

We looked at production practices at baseline to inform the content of the extension course, aiming to target practices which were already used by a significant portion of participating households. This served as a guide for identifying regionally-appropriate practices, and provides heterogeneity in the level of experience among members of the chat groups. All baseline measures pertain to practices employed on the respondent's main maize plot (MMP). 26% of households applied some organic fertilizer on their MMP in 2020, including manure, compost, crop residue, and transfer of forest soil. 16% intercropped maize with a legume on their MMP, and 17% planted a legume in rotation or as a cover crop. According to recall data collected in 2021, 32% of households planted a legume somewhere on their farm in 2020. For reference, fewer than 5% of households used inorganic fertilizers in 2020, which is typical for Tanzania and many regions of SSA.

5.1.2 Summary of Outcome Variables

In Table 3, we present summary statistics for each outcome variable at baseline in 2020 and endline in 2021. As a result of our decision to send extension messages through ShambaChat to all study participants, both treatment and control, we are likely to see an impact on certain outcome variables, particularly adoption of the targeted practices, across all households from 2020 to 2021. These year effects are suggested by the difference estimates in Column 5 of Table 3, for which we test the significance with t-tests of the sample means in 2020 and 2021. However, since we do not control for individual fixed-effects here, or macro-level shocks occurring during the study period (for example, the COVID-19 pandemic), we cannot and do not attempt to attribute this effect to the extension campaign. Still, it is worth noting that 27% of maize-growing households intercropped maize with a legume on their main maize plot (MMP) in 2021, compared to only

16% in 2020, representing a nearly 75% increase in households who intercropped over the study period. Additionally, although the number of households who found or produced organic materials on their farm decreased substantially in 2021, those who did were more than twice as likely to allocate these resources to the production of organic fertilizer in 2021. Interestingly, application of organic fertilizer decreased 77%, with 26% of maize-growing households applying organic fertilizer on their MMP in 2020 compared to only 6% in 2021.

Many of the behavioral outcomes we measured also increase in 2021 relative to their baseline values. The average knowledge score increased by 1.9 points on a 16 point scale, generalized PSE scores increased 0.39 points on average on a 5 point scale, and PSE over soil fertility, profit, and food security outcomes each increased modestly as well. To the extent that this effect is attributable to the ShambaChat extension content, we may be seeing that as farmers engage with the messages and discussion prompts, even if they are not chatting with each other, they develop a sense of self-efficacy surrounding the targeted practices and retain knowledge from the course. In the following section we are able to disentangle the year effect from the treatment effect using a model of first-differences with panel data and year fixed-effects.

Table 3: Summary Statistics for Outcome Variables at Baseline and Endline

		2020			**2021**		
Adoption Outcomes:	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**	**Difference**
Intercrop w legume on MMP (1)	310	0.16	0.37	330	0.27	0.45	0.111***
Intercrop w legume on MMP (2)	310	0.11	0.31	330	0.20	0.40	0.091***
Other legume practices	310	0.16	0.37	330	0.11	0.31	-0.052
Legumes on farm	410	0.32	0.47	410	0.31	0.46	-0.007
Produced organic materials	310	0.64	0.48	330	0.22	0.41	-0.417***
Made organic fertilizer on-farm	197	0.22	0.42	73	0.60	0.49	0.379***
Applied organic fertilizer on MMP	310	0.26	0.44	330	0.06	0.23	-0.204***

Behavioral Outcomes:	N	2020 Mean	SD	N	2021 Mean	SD	Difference
RA Knowledge score	369	2.95	2.41	410	4.85	2.77	1.900***
General PSE score	369	3.31	0.81	410	3.67	0.87	0.366***
PSE: Soil Fertility	369	3.85	1.21	410	4.15	0.98	0.298**
PSE: Profits	369	3.79	1.20	410	4.03	1.08	0.238**
PSE: Food Security	369	4.06	1.22	410	4.24	1.02	0.174*
PSE: Furrowed Ridges	356	2.31	1.20	397	2.44	1.23	0.129
PSE: Seed Spacing	169	1.18	0.52	190	1.32	0.72	0.138
PSE: Intercropping	302	1.29	0.73	289	1.52	0.98	0.231*
PSE: Poultry Manure	367	1.99	1.18	397	2.10	1.17	0.114

5.2 Treatment Effects

We are interested in understanding the effect of incorporating a group chat feature in an SMS messaging campaign on participants' engagement with extension information. To reiterate, all households in our study received extension information and discussion prompts over SMS, and *treated households were also assigned to a 5 person chat group* where they could discuss the new information by text with other farmers in real time as they received it. In this section, we estimate the effect of this treatment on adoption and behavioral outcomes. We follow an intent-to-treat (ITT) analysis across all models employed, where the independent variable is always the randomly allocated treatment indicator.

5.2.1 Technology Adoption

The regenerative agriculture methods introduced through the extension campaign can be grouped into (1) legume practices and (2) organic materials practices, and contain the 7 outcome variables described in Section 4.5. We measure the effect of treatment on each of these variables using the following first differences equation estimated by ordinary least squares (OLS) linear probability model with robust standard errors clustered at the village level:

$$\Delta y_{ij} = \alpha_0 + \beta_j TREAT_i + \Delta\varepsilon_i \tag{2}$$

where Δy_i are the difference in each of j outcome variables measured at endline (2021) and baseline (2020), $TREAT_i$ is an indicator of treatment (one for treated households; zero otherwise), ε_{iv} is an error term, and α_0 is a constant. We are interested in the coefficients β_j, which measure the average effect of the treatment on the outcome variable specified. A significant β_j would imply that the treatment had an effect on outcome j. Standard errors are clustered at the village level to account for potential correlation of outcomes within villages. Since all household characteristics are balanced across treatment and control groups, we do not include a vector of controls in this model.

Our results, presented in Table 4 and Table 5 indicate that treatment had a positive impact on legume intercropping, statistically significant at the 5% level, as measured by both of our indicator variables. The first variable, found in Column 1 of Table 4 takes a value of one for all respondents who listed a legume crop as something they planted along with maize on their main maize plot (MMP). The estimate implies that treated households were 14.5% more likely plant a legume on their MMP in 2021 relative to control households in 2021. The second intercropping indicator, found in Column 2 of Table 4, is based on respondents' answer to the question "Did you intercrop maize with a legume on your MMP this year?". The two measures differ slightly as some farmers may have planted a legume alongside maize without recognizing this practice to be intercropping – see Section 4.5 for details. By this measure, treated farmers were 8.4% more likely to intercrop. A possible explanation for the lower treatment effect on the second indicator is that farmers in the chat groups typically did not use the word "intercropping", but rather listed various leguminous crops that they had tried or heard about planting alongside maize. Both treated and control farmers learned explicitly about intercropping through the SMS messages. While not statistically significant at traditional levels, we note that the coefficients on other legume practices and legumes on farm are both negative, perhaps suggesting that the treatment encouraged farmers to plant legumes alongside maize instead of elsewhere on their farms.

Table 4: Effect of Treatment on Adoption Outcomes – Legume Practices

VARIABLES	(1) Intercropping 1	(2) Intercropping 2	(3) Other Legume Practices	(4) Legumes on Farm
Treated	0.145**	0.0835**	-0.0766	-0.0534
	(0.0634)	(0.0400)	(0.0512)	(0.0402)
Constant	0.0472	0.0472	-0.0157	0.0199
	(0.0486)	(0.0422)	(0.0407)	(0.0349)
Observations	257	257	257	410
R-squared	0.017	0.007	0.007	0.005

Note: The number of observations in Columns 1 – 3 reflects the number of respondents who cultivated maize in both time periods. Respondents who did not cultivate maize were not asked about these legume practices. Robust standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

There are no significant results for any of the organic materials practices, and overall we find that significantly fewer farmers across treatment and control groups produced or applied organic fertilizers in 2021 compared to 2020. However, the large positive coefficient on "made organic fertilizer" presented in Column 2 of Table 5 suggests that perhaps farmers in the treatment groups were more likely to allocate their on-farm organic materials as fertilizers, another topic discussed frequently in the chat groups. This coefficient is significant at the 11% level.

Table 5: Effect of Treatment on Adoption Outcomes – Organic Materials Practices

	(1)	(2)	(3)
VARIABLES	**Organic Materials**	**Made Organic Fertilizer**	**Organic Fertilizer - MMP**
Treated	0.00999	0.323	0.0130
	(0.0848)	(0.198)	(0.0632)
Constant	-0.433***	0.0769	-0.228***
	(0.0738)	(0.175)	(0.0600)
Observations	257	43	257
R-squared	0.000	0.055	0.000

Note: Observation count for Column 1 and 3 reflects number of respondents who cultivated maize in both years. The count for Column 2 reflects the number of respondents who collected or produced organic materials in both years.
Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

5.2.2 Belief Updating

We measure a series of behavioral outcomes in an effort to understand the belief updating process farmers undergo when they receive new information, chat about it with others, and decide whether or not to adopt new practices. These include a knowledge score about the content of the SMS extension course, and various measures of perceived self-efficacy (PSE) associated with adoption of the key practices discussed – see Section 4.5 for details. Knowledge score and general PSE, measured with a continuous outcome variable (or in the case of knowledge score, a well-ordered categorical variable with many categories and a normal distribution) are well suited to first-differences estimation with OLS, and we model these using the specification described above in Section 5.2.1, equation (2). The results of these regressions are presented in Tables 6 – 8. As we see, the effect of treatment on these outcomes is not statistically significant at traditional levels. We discuss the implications and possible explanations of these results in Section 6.

Table 6: Effect of Treatment on Behavioral Outcomes – General PSE

VARIABLES	(1) General PSE
Treated	0.0422
	(0.119)
Constant	0.350***
	(0.0788)
Observations	369
R-squared	0.000

Note: The observation count reflects the number of respondents with non-missing responses for both 2020 and 2021. There are no missing observations in 2021, so all missing are those who did not complete Part 2 of the survey in 2020. Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 7: Effect of Treatment on Behavioral Outcomes – Knowledge

VARIABLES	(1) Knowledge Score
Treated	-0.551
	(0.503)
Constant	2.156***
	(0.452)
Observations	369
R-squared	0.007

Note: The observation count reflects the number of respondents with non-missing responses for both 2020 and 2021. There are no missing observations in 2021, so all missing are those who did not complete Part 2 of the survey in 2020Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

A key variable of interest to our study is perceived self-efficacy (PSE) in the domain of soil fertility management. There is no standardized measurement for domain-specific PSE, only general guidelines from the psychology literature (Bandura, 2006; Schwarzer and Renner, 2009) for creating appropriate scales. We constructed two domain-specific PSE modules to investigate this trait among study participants – see Section 4.5 for a full discussion of our metrics. Both modules asked respondents to select a value from a Likert scale, resulting in categorical, non-continuous outcome variables. There is debate over whether Likert scale dependent variables can be treated as continuous and estimated with a linear probability model, as we have done for the other variables in our analysis (Sullivan and Artino, 2013). We nevertheless report in Tables 8 – 9 the first-differences estimation specified in equation (2) using OLS regression with robust standard errors clustered at the village level. We find a positive coefficient of 0.311 on intercropping PSE, significant at the 10% level, indicating that treatment increased this score by .31 units on a four-point scale. No other measures are significant.

Table 8: Effect of Treatment on Behavioral outcomes - Task-Specific PSE

VARIABLES	(1) Furrows	(2) Seed Spacing	(3) Intercropping	(4) Manure
Treated	0.234	0.212	0.311*	0.129
	(0.191)	(0.161)	(0.173)	(0.218)
Constant	-0.0368	-0.128	0.120	0.0520
	(0.172)	(0.116)	(0.124)	(0.195)
Observations	346	75	217	355
R-squared	0.005	0.019	0.014	0.002

Note: N is the number of observations who are non-missing in both years. Observations are missing if they have already adopted a given practice on their farm (so answered N/A to the PSE question regarding capability of adopting)
Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 9: Effect of Treatment on Behavioral Outcomes – Outcome-Specific PSE

	(1)	(2)	(3)

VARIABLES	Soil Fertility	Profits	Food Security
Treated	-0.0767	-0.0902	-0.109
	(0.157)	(0.179)	(0.182)
Constant	0.324**	0.285*	0.246*
	(0.158)	(0.153)	(0.144)
Observations	369	369	369
R-squared	0.001	0.001	0.001

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

However, these results should be interpreted with caution, particularly in the case of the task-specific PSE measures for which the Likert scale has only four items – an oversight in the design of our survey instrument (Rickards et al., 2012). For this reason, we also evaluate these outcome variables using an ordered logistic regression model with random effects given by:

$$P(Y_{it} > k \mid X_{it}, \nu_i) = H(\beta X_{it} + \nu_i - k_k) \tag{3}$$

where ν_i is an iid error term, $k_1, \dots, k_{K-1}$ are the possible levels taken by the outcome variable Y_{it} (as above), and $H(\cdot)$ is a logistic cumulative distribution function. Fixed-effects models are often preferred to random-effects models, as the latter requires a stricter condition on the individual-specific error term. Namely, the individual-specific effects must be uncorrelated with the independent variable. In our case, the randomization of households into treatment and control group should ensure that this assumption is valid, as there is no reason for any characteristics of the individual to be correlated with their treatment status – the independent variable in our case. If this assumption holds, the random-effects model is more efficient than fixed-effects (Woolridge, 2015). The results of this model, presented in Tables 10 – 11, corroborate the first-difference estimations. We find a positive treatment effect on task-specific PSE for intercropping, significant at the 1% level. The coefficient is not straightforward to interpret, but the positive sign tells us that treated households rate their PSE in the domain of intercropping higher relative to the control. No other results are significant, but the signs on all coefficients match those from the linear model.

Table 10: Effect of Treatment on Task-Specific PSE – Ordered Logit with Random-Effects

VARIABLES	**(1) Furrows**	**(2) Seed Spacing**	**(3) Intercropping**	**(4) Manure**
Treatment	0.0724	0.494	0.715***	0.209
	(0.208)	(0.423)	(0.224)	(0.250)
Year = 2021	0.135	0.332	0.268	0.116
	(0.230)	(0.463)	(0.327)	(0.284)
Observations	753	359	591	764
Number of respondent_id	407	284	374	409

Note: Number of respondent ID counts all the households who have a non-missing value for either 2020 or 2021 (or both). The only ones that are dropped are those missing the value for both years. N (observations) counts the number who are non-missing in 2020 plus the number who are non-missing in 2021.
Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 11: Effect of Treatment on Outcome-Specific PSE - Ordered Logit with Random-Effects

VARIABLES	**(1) Soil Fertility Outcomes**	**(2) Profit Outcomes**	**(3) Food Security Outcomes**
Treatment	-0.221	-0.265	-0.204
	(0.272)	(0.238)	(0.215)
Year = 2021	0.534**	0.508**	0.291
	(0.258)	(0.229)	(0.249)
Observations	779	779	779
Number of respondent_id	410	410	410

Note: Number of respondent ID counts all the households who have a non-missing value for either 2020

or 2021 (or both). The only ones that are dropped are those missing the value for both years. N (observations) counts the number who are non-missing in 2020 plus the number who are non-missing in 2021.
Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

5.3 Robustness Check – Effect of Treatment on the Treated (TOT) Analysis

The ITT analysis above likely underestimates the effect of participation in the ShambaChat group chats, as many treated households did not actively use the group chat feature. Households may have still benefited from receiving messages or reading chatter in their respective group chats, but in some cases there was no activity in the chat group, rendering the experience of treated households in these groups identical to that of control households. To capture the effect of treatment on the treated – i.e. the effect of being included in an active group chat – we would like to regress each adoption and behavioral outcome variable on the level of activity in participant *i'*s chat group. This cannot be done directly because farmers who are more active may be more predisposed to adoption, resulting in an overestimation of treatment effect. Instead, we define a binary variable equal to 1 for active chat groups (groups in which at least one member participated) and instrument this with the randomly allocated treatment variable used in the analysis above. Since untreated households necessarily have a group message count of zero, there is strong correlation between treatment and group message count, indicated by a Pearson correlation coefficient of 0.94, making this a valid choice of instrument in terms of relevance. Being randomly allocated, the treatment variable also meets the exclusion restriction for valid IVs.

The results of these IV regressions for adoption outcomes are reported in Tables 12-13, and are consistent with the results of the ITT analysis in Section 5.2. We find slightly higher coefficients on both intercropping measures when we use this approach, which is to be expected given that we are now looking explicitly at groups that were actively participating in the treatment.

In the interest of space we do not report the results of the TOT analysis on behavioral outcomes, but these are all consistent with the ITT analysis and available upon request from the author. Only the task-specific PSE measure intercropping for intercropping is significant.

Table 12: Effect of Treatment on Adoption Outcomes with IV – Legume Practices

VARIABLES	(1) Intercropping 1	(2) Intercropping 2	(3) Legumes on Farm	(4) Other Legume Practices
Active chat group	0.161**	0.0928**	-0.0584	-0.0851
	(0.0715)	(0.0446)	(0.0440)	(0.0566)
Constant	0.0447	0.0458	0.0205	-0.0144
	(0.0489)	(0.0425)	(0.0351)	(0.0412)
Observations	257	257	410	257
Number of respondent_id	257	257	410	257

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 13: Effect of Treatment on Adoption Outcomes with IV – Organic Materials Practices

VARIABLES	(1) Organic Materials	(2) Made Organic Fertilizer	(3) Organic Fertilizer - MMP
Active chat group	0.0111	0.334	0.0144
	(0.0943)	(0.207)	(0.0702)
Constant	-0.433***	0.0769	-0.229***
	(0.0747)	(0.175)	(0.0608)
Observations	257	43	257
Number of respondent_id	257	43	257

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

5.4 Spillover Effects

There is potential for spillover of treatment effects to untreated households if chat group participants discuss their experience with neighbors, or if adoption of the targeted practices by treated households encourages others in the community to adopt as well – clearly a desired outcome of any agricultural education initiative (Feder et al., 2004). If these effects are present in treatment villages, our results represent a lower-bound estimate of the impact of treatment. For this reason, we included a subset of control households in randomly selected control villages, in which no households were selected for treatment (i.e. given access to the group chat feature of ShambaChat). Comparing treated households directly to control households in control villages would give us a pure treatment effect, but doing so decreases our sample size significantly. To test for spillover effects, we estimate the following first-differences equation using OLS with robust standard errors clustered at the village level:

$$\Delta y_{ij} = \alpha_0 + \sum_{k=0}^{2} \theta_{kj} TREAT_i^k + \Delta \boldsymbol{X}_i + \Delta \varepsilon_i \tag{4}$$

where y_{ij} takes the endline value of each outcome variable, j, regressed on a series of three dummy variables, $TREAT_i^k$, corresponding to treated households ($k = 2$), control households in treatment villages ($k = 1$), and control households in pure control villages ($k = 0$), respectively. A significant θ_{1j} coefficient would indicate the presence of spillover effects, implying that control households in treatment villages absorbed some of the treatment effect on outcome j from neighboring households. However, referring to the balance table (Table 2) from Section 4.7.2, we see that after attrition the control households in treatment vs control villages are not well-balanced at baseline across several outcome variables, namely legumes on farm, making organic fertilizer, PSE over soil fertility outcomes, and PSE over a seed spacing task. We must therefore take care in attributing any effect on these outcomes to spillovers from treatment. Additionally, control households are unbalanced in land-owned and ownership of MMP. We therefore include these variables in a vector of controls $\boldsymbol{X}_i$. We find evidence of spillover effects, indicated by significant θ_1 coefficient in several adoption outcomes, presented in Tables 14 – 15, namely the first legume intercropping measure (Table 14, Column 1) and the indicator for making organic fertilizer (Table 15, Column 2). Making organic fertilizer was not balanced at baseline, with control households in treatment villages significantly *less* likely to produce or find organic materials on their farms relative to control households in control villages, so this spillover effect may actually be stronger than the coefficient implies. These results suggest that control households in treatment villages may have absorbed some impact of the treatment through watching their neighbors adopt intercropping practices or discussing their experience of the ShambaChat group chats. In this case, our estimate of the treatment effect on these outcome reflects a lower-bound.

We also note the significant θ_2 coefficients for both legume intercropping measures, as well as for making organic fertilizer, which indicate positive treatment effects on these outcomes for treated households relative to control households in control villages. This suggests that the treatment effects we report in Section 5.2.1 may underestimate the true impact of treatment due to the presence of spillovers in treatment villages. We do not find any spillover effects across behavioral outcomes.[6]

Table 14: Spillover Effects on Adoption Outcomes – Legumes

[6] In the interest of space, these are not reported, but all results are available upon request from the author.

VARIABLES	(1) Intercropping 1	(2) Intercropping 2	(3) Other Legume Practices	(4) Legumes on Farm
TREAT = 1	0.168*	0.113	0.0440	-0.00742
	(0.0891)	(0.0917)	(0.0799)	(0.0882)
TREAT = 2	0.266***	0.162**	-0.0571	-0.0437
	(0.0807)	(0.0778)	(0.0797)	(0.0873)
Land Owned (acres)	0.00703***	0.00207	-0.00514**	0.00154
	(0.00258)	(0.00263)	(0.00199)	(0.00153)
Owns MMP	-0.0995	-0.178	0.210*	-0.138*
	(0.153)	(0.115)	(0.119)	(0.0685)
Constant	-0.0186	0.127	-0.207*	0.156
	(0.143)	(0.110)	(0.113)	(0.0950)
Observations	257	257	257	330
R-squared	0.053	0.020	0.032	0.014

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 15: Spillover Effects on Adoption Outcomes – Organic Materials

VARIABLES	(1) Organic Materials	(2) Made Organic Fertilizer	(3) Organic Fertilizer MMP
TREAT = 1			
	0.0194	0.546*	0.125
TREAT = 2	(0.152)	(0.271)	(0.138)
	0.0281	0.736**	0.102
Land Owned (acres)	(0.137)	(0.277)	(0.131)
	0.00433	-0.00756	0.00524***
Owns MMP	(0.00266)	(0.0166)	(0.00111)
	0.0911	0.433	0.0470
Constant	(0.164)	(0.790)	(0.130)
	-0.563**	-0.705	-0.391**
	(0.213)	(0.830)	(0.191)
Observations	257	43	257
R-Squared	0.009	0.119	0.026

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

6. Discussion

6.1 Summary

To summarize, we find significant and positive treatment effects on adoption of intercropping practices, as measured by two indicators, and on domain-specific PSE over an intercropping task. We find no effect on other outcome variables, including adoption of organic materials practices, knowledge retention, other metrics of PSE, subjective probability distribution over soil fertility, profit, and food security outcomes, or welfare outcomes including maize yields, assets, and food security (not reported). The presence of spillovers, detected for multiple adoption outcomes, suggests that our treatment benefited untreated households through community networks. In this section we discuss possible explanations for our findings in the context of how farmers actually engaged with the treatment. We address methodological limitations that may have impacted our results, as well as broader limitations to the use of ICTs for farmer-to-farmer extension and peer learning.

6.2 Use of the ShambaChat Platform

The ShambaChat extension campaign was divided into three rounds, each lasting for one month and covering different (but overlapping) regenerative agriculture practices and agro-ecological principles. We found that participation in the first round, which focused on legume-maize intercropping, was highest, with 996 messages sent by farmers in the group chats. We analyzed the content of the messages using simple natural language processing techniques in Python to gain an understanding of the ShambaChat user experience. To reiterate, treated farmers received extension broadcasts and discussion prompts from our team of researchers, tagged with "SUA" for the agricultural university in Morogoro which farmers are familiar with, as well as messages from other farmers in their chat group, tagged with the first three letters of the sender's name. A reply to either message type would be forwarded to all five chat group members. 655 of the texts sent by farmers during the first round were direct responses to extension broadcasts, while the remaining 324 texts were direct replies to another member of the chat group, indicating that – at least in some groups – there was active dialogue between members. Figure 1 shows the breakdown of the types of messages sent by farmers. Most texts contained questions or advice (including answers to questions posed by other farmers or in our discussion prompts), or articulated challenges regarding the proposed practices or other factors affecting production such as pest or weather problems. Other messages contained logistical questions about how to navigate the ShambaChat platform, and introductions. Some farmers repeatedly introduced themselves, suggesting they did not understand that their chat group consisted of the same five members for the duration of the course.

Figure 1: Breakdown of Messages Sent by Farmers in First Round of Extension

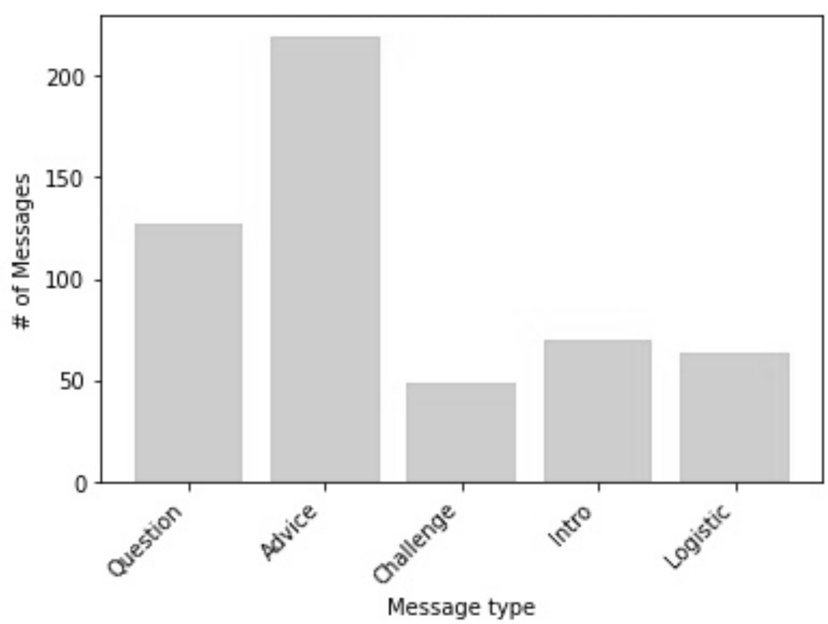


Figure 2: Topics Most Frequently Discussed by Farmers in First Round of Extension

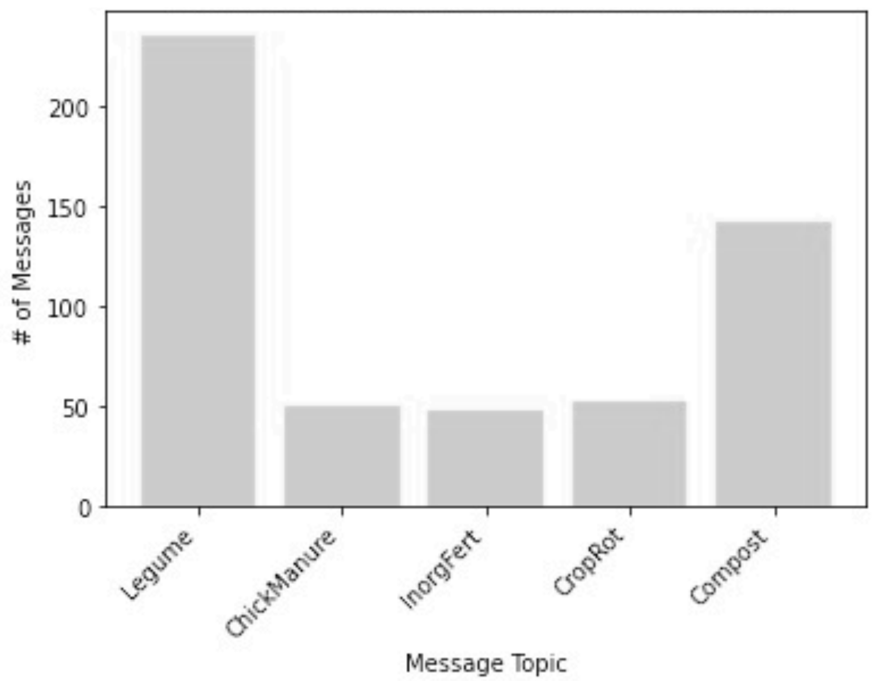
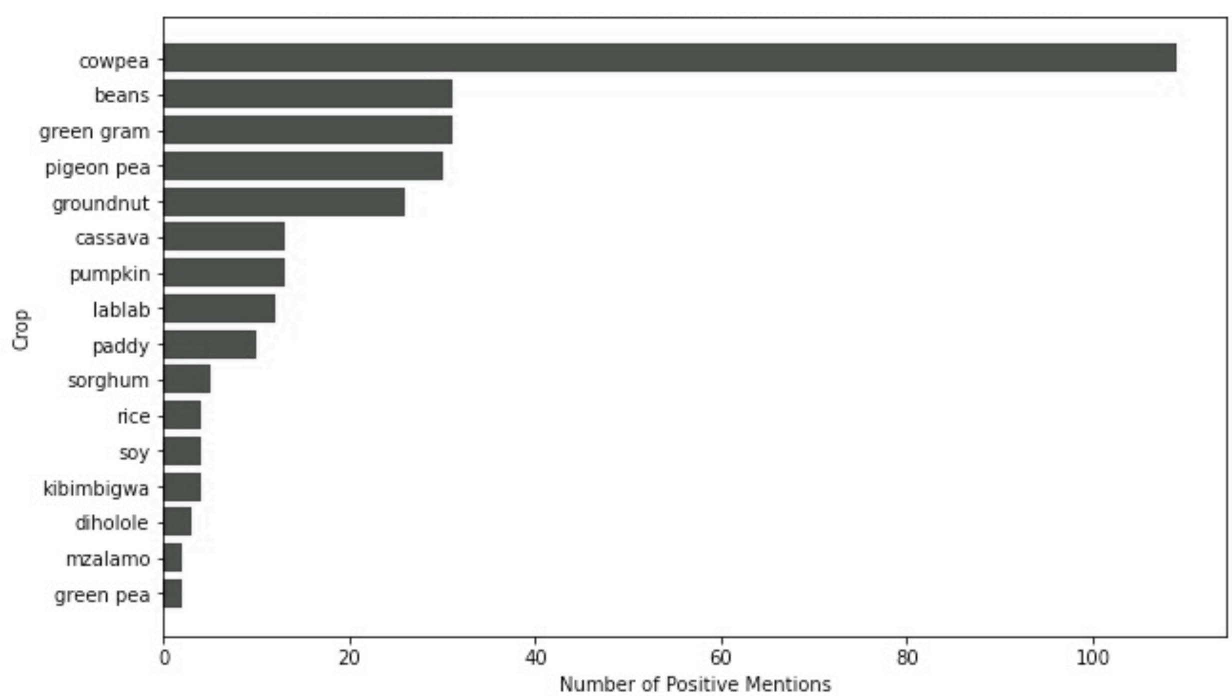


Figure 3: Frequency of Crops Mentioned by Farmers in First Round of Extension (excl maize)



A potential issue arises if farmers share misinformation in the group chats or contradict the content of the extension broadcasts, but we do not see much evidence of this occurring. In fact, 213 of the messages sent by farmers directly reinforced the extension content, while only 14 contradicted it. Only 7 messages contained objectively inaccurate information. 53 messages explicitly expressed intent to try one of the targeted practices for the first time. As we see in Figures 2 and 3, farmers sent over 200 messages about legumes – the focus of the first round of extension – and listed 14 varieties by name. This is an indication that farmers were interested in the extension content and used the group chats to deepen their engagement with the material by discussing it with their peers.

During the second round of the course, which focused on collecting on-farm organic materials and making compost, we saw a stark decline in activity in the group chats. There was a 6 week hiatus between the rounds, so it is likely that many participants lost interest during this time, and others may have lost access to their SIM card or phone. The message content from farmers was extremely limited, containing mostly introduction messages and thank you notes in response to extension broadcasts. The case was similar for the third round, which coincided with the maize harvest and focused on practices for leaving crop residues and preparing fields for the next season. We do not formally estimate the relationship between the level of group chat activity and effect of the treatment on adoption or other outcomes, but it is interesting to note that the high volume of messages and discussion surrounding the content of the first round corresponds to the treatment effect we find on adoption of intercropping practices and PSE over the intercropping task. The complete lack of discussion during the later rounds almost precludes us finding a treatment effect on other adoption variables, consistent with our null findings regarding adoption of organic materials practices and associated behavioral outcomes.

6.3 Impact of the Treatment and Methodological Limitations

If we consider the first round of extension in isolation, we see evidence of a role for PSE in the belief-updating process through which peer learning leads to adoption. Farmers engaged with information about legume intercropping through discussion with peers in a group chat, after which their PSE regarding their ability to perform an intercropping task increased, along with their likelihood of adopting the practice on their own farm. However, an identification problem emerges, as we measured endline PSE only after the adoption had taken place. It is therefore possible that adoption was spurred by some other mechanism present in the treatment, and that successful implementation of intercropping in fact contributed to the increase in PSE rather than the other way around. According to Bandura (1977, 1986), PSE is influenced most strongly by personal mastery experiences, making this interpretation of the direction of causality equally plausible. Perhaps there is mutual causality going on, with PSE playing a role on both sides of the adoption decision: social learning kickstarts a virtuous cycle wherein increased PSE from exposure to peer role models empowers farmers to adopt challenging practices, which, when completed successfully, increase PSE further through the experience of mastery. Further research could resolve this by measuring PSE after the new information is received and discussed, but before the adoption decision is made.

As previously stated, we speculate that PSE might increase from participation in the group chats simply as a result of increased exposure to the experience and attitudes of peers. However, a distinct role model effect implies that someone in the group is more experienced in the relevant domain. We took this into consideration when designing the intervention, as described in Section 4.3. Each chat group contained one farmer who had experience with legume intercropping at baseline, and one who had experience with a soil conservation practice including grass strips, ridges, bench terraces, drainage channels, or water catchment. We chose these selection criteria before the extension course was finalized, and in the end we did not end up including the soil conservation practices listed here, changing the focus instead to organic material cycling. This meant that groups only had a role model for intercropping, which is consistent with the fact that our treatment effects are stronger for the intercropping outcomes, including intercropping PSE. Further research is needed to distinguish the role model effect from the social learning effect observed from a group of peers with similar experience, perhaps building on this study to include a block of group chats with and without designated role models.

Our failure to measure outcome variables at the end of each round (due to budget and time constraints) may also have implications beyond the mutual causality problem described above. Since activity in the group chats dropped to almost zero after the first round of extension, the experience of treated and control farmers was close to identical for much of the intervention, meaning our endline measurements were effectively taken six months after the end of treatment. Such a gap between treatment and evaluation could make a big difference in the levels of the outcome variables we measure, particularly for behavioral outcomes like knowledge retention and PSE. For example, in their study of the role model effect in Digital Green's video-mediated extension program, Bernard et al. (2015; 2019) find an increase in external locus of control when they survey participants immediately after the intervention, but a much weaker effect when they follow up with the same questions six months later. It is therefore possible that we may have seen more of a treatment effect on our behavioral indicators had we been able to evaluate after each extension round.

Evaluating behavioral outcomes objectively is also a challenge, as there are not always agreed upon metrics available or replicable in the literature. For instance, domain-specific PSE – by definition – does not cut across domains of functioning, so any metric must be constructed in reference to the relevant set of tasks or outcomes under review. Since this study is the first to measure PSE over intercropping and regenerative agriculture tasks, or even agriculture more generally, we had to develop our own module for eliciting this trait. We took care to draw from the psychology literature on elicitation of domain-specific PSE, which is fairly well-developed particularly in health and education domains (Bandura, 2006; Chen et al., 2001; Schwarzer and Renner, 2009; Wuepper and Lybbert, 2017). However, the metrics we constructed are not validated by psychologists or any external study, meaning we cannot rule out the possibility that treatment did impact these variables though we failed to detect the effect. For example, Bandura (2006) notes that a valid scale should reflect gradations of challenge by measuring efficacy beliefs for a series of progressively more challenging sub-tasks, which we were not able to do because we had not finalized the extension course at the time of baseline data collection and could not anticipate what the content would be to this level of detail. We also face econometric challenges when analyzing the data from the four or five item Likert scales we used in these measures, as discussed in Section 5.2.2.

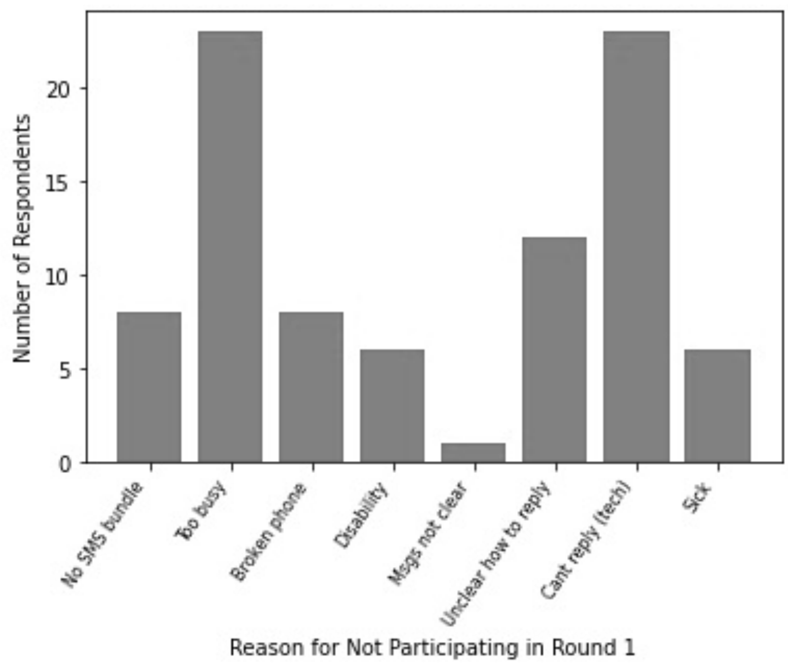
7. Conclusion

7.1 Limitations of ICTs for Peer Learning

Promoting adoption of complex agriculture technologies like RA requires an approach to extension that centers farmers as innovators and nodes of communication in the design and dissemination of relevant practices. Through experimentation and observation of others, farmers update their beliefs about likely outcomes associated with adoption, and exposure to success stories and positive attitudes increases farmers' confidence and willingness to try something new. The role of the extension service is therefore to facilitate the flow of information between farmers, and provide a space for robust dialogue around personal experiences with adoption. If peer learning processes operate through the mechanism of vicarious experience, whereby agents update their beliefs about their own capabilities after observing the success (or failure) of a relatable peer, extension campaigns should be designed to facilitate these experiences. F2FE initiatives have had varying degrees of success with this, depending in part on their ability to establish meaningful connections among participating farmers.

If these conditions for impactful F2FE are difficult to meet even for in-person initiatives, it is not surprising that we face challenges translating them to a digital learning environment. Anyone who has engaged with an online community, especially one composed of strangers, is aware of the communication pitfalls that arise when expressing complex ideas to an unknown audience. Considering these same dynamics playing out on feature phones, with participants who likely have varying degrees of technological literacy, it is easy to see why meaningful connections or robust dialogue may have been difficult to maintain. We surveyed 90 farmers from the treatment group who did not participate actively in the group chats after the first round of extension, to gain insight into why they didn't engage. Figure 4 gives a breakdown of the most commonly cited reasons. Many farmers told us they were too busy to reply, could not reply because of broken technology, or did not understand how to reply to the messages. All of these problems reveal a pattern common in ICT extension, where providers fail to consider the interests, needs, and technical capacities of the farmers they hope to reach (Wyche and Steinfield, 2016).

Figure 4: Reasons Most Frequently Cited for Not Participating in First Round of Extension



7.2 Conclusion and Policy Recommendations

Even where technology barriers can be overcome, it seems unlikely that ICTs will ever be a perfect substitute for in-person F2FE, nor will they replicate the dynamics present in community-based social networks. Of course, the present study is limited to a very rudimentary form of technology – SMS communication on feature phones – and we do not extrapolate our findings to more complex interventions. Still, for many farmers in SSA, feature phones are the predominant form of ICT available for the time being, and making use of this tool to overcome harmful information constraints should be an essential part of any development strategy for the region. The positive performance of the ShambaChat platform during the first round of extension leaves us optimistic regarding the potential benefits of a similar extension tool. We saw active discussion between farmers surrounding the content of the course, and measured a significant impact on adoption of the central practice covered during that round - intercropping. Moreover, we detected significant spillover effects, suggesting the treatment benefited other farmers through community networks. Providing extension through ShambaChat is low-cost and logistically straight-forward relative to in-person F2FE, and our results, though modest, support further development of effective uses for ICT to facilitate connections between farmers. The failure of ShambaChat to keep users engaged over multiple extension rounds points to a need for future interventions to seek guidance from farmers about what topics are of interest to them, and how to tailor the extension tool to their specific goals and level of technology and technological literacy.

Our investigation of the behavioral mechanisms by which social learning leads to adoption is rudimentary, and further collaboration between social psychologists and economists is needed to develop and validate methods for eliciting and influencing domain-specific PSE. The significant result we find for intercropping PSE contributes to a growing body of literature linking adoption behavior to internal constraints like self-efficacy beliefs (Abay et al., 2017; Bernard et al., 2015, Carter 2016, Malacarne 2018; 2019; McGinty et al., 2008; Taffesse and Tadesse, 2017; Ung et al., 2016, Wuepper and Lybbert, 2017). If our results are corroborated, they can be used to support the design of participatory learning interventions that help farmers build confidence by sharing experience and troubleshooting complex information with the help of relatable role models and peers.

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APPENDIX A – Attrition

We conduct two tests to determine if attrition is random. First, following Haushofer and Shapiro (2016) we verify that attrition is not correlated with treatment assignment by estimating the following equation using OLS, with standard errors clustered at the village level:

$$attrition_i = \alpha_i + \sum_{k=0}^{2} \theta_k TREAT_i^k + \varepsilon_i \tag{1}$$

where $attrition_i$ takes a value of one for farmers we did not reach at endline in 2021, and zero otherwise, and $TREAT_i^k$ takes a value of one for farmers assigned to treatment arm k, where $k = 0$ are control households in pure control villages (the omitted category), $k = 1$ are control households in treatment villages, and $k = 2$ are treated households. The results presented in Table A1 indicate that attrition is randomly distributed among the three treatment groups.

Table A1: Probability of Attrition by Treatment Group

VARIABLES	**(1)** **Attrited**
Control in treatment village	0.000132
	(0.0684)
Treatment	-0.0306
	(0.0569)

Constant	0.247***
	(0.0450)
Observations	531
R-squared	0.001

Robust standard errors in parentheses
Standard errors are clustered at the village level.
*** p<0.01, ** p<0.05, * p<0.1

Next, we check whether any relevant household demographics or outcome variables are correlated with attrition by regressing each variable on the binary variable *attrition* defined in equation (1) above. We estimate the following equation using OLS, with standard errors clustered at the village level:

$$y_i = \alpha_0 + attrition_i + \varepsilon_i \tag{2}$$

The results of these regressions, presented in Table A2 confirm that attrition is not correlated with any relevant variables.

Table A2: Effect of Attrition on Outcome Variables

VARIABLES:	**(1) ATTRITION:**
Age of hh head	0.001
	(0.001)
Gender of hh head	0.022
	(0.057)
Education completed by hh head	0.002
	(0.008)
Dependency ratio	0.0
	(0.0)
Food insecurity index	-0.009
	(0.011)

Land owned (acres)	0.001 (0.003)
Do you own your MMP?	0.008 (0.064)
Asset Index	-0.001 (0.011)
Remoteness	0.001 (.011)
Maize yield (kg/acre)	-0.0 (0.0)
Intercrop w legume on MMP (1)	-0.076 (0.052)
Intercrop w legume on MMP (2)	-0.139 (0.057)
Other legume practices	0.039 (0.049)
Legumes on farm	0.015 (0.011)
Produced organic materials	0.025 (0.045)
Made organic fertilizer on-farm	-0.037 (0.059)
Applied organic fertilizer MMP	0.021 (0.032)
RA knowledge score	0.001 (0.001)
General PSE score (mean)	-0.037 (0.026)
PSE Outcomes: Soil Fertility	0.005 (0.018)
PSE Outcomes: Profits	0.004 (0.216)
PSE Outcomes: Food Security	-0.004 (0.017)
PSE Tasks: Furrowed Ridges	0.029 (0.016)
PSE Tasks: Seed Spacing	-0.035 (0.054)
PSE Tasks: Intercropping	-0.003 (0.03)
PSE Tasks: Poultry Manure	-0.003 (0.014)
SPD over soil fertility outcomes	0.0 (0.0)
SPD over profit outcomes	0.0 (0.0)

SPD over food security outcomes	0.0
	(0.0)

Robust standard errors in parenthesis.
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Appendix B: Content of Extension Course

Round 1 Extension Content:	**Discussion prompts:** *Messages in italics are sent only to chat-group participants*	**Date of sending:**
Hello, you participated in a research study in August 2020. As part of this study, you have now been selected to participate in a free course to help improve your soil, offered by SUA over SMS.. You will receive text messages with tips. The course is in 3 units: 2/1 – 2/28; 4/1 – 4/31; 7/1 – 7/31 If you participate, you will receive an unlimited texting plan each month until August 2021 as compensation for your time. Researchers will ask you some questions about the course in August, 2021. If you do NOT wish to participate, please reply "NO" to this message.	*You are also invited to a group chat with 5 maize farmers from Morogoro who have similar nitrogen deficiencies in their soil.* *You can discuss the course and any agricultural practices. You now have an unlimited text plan on your phone, so messages are free.* *Only the principal investigators at SUA and McGill University will be able to link your responses with your name.* *They will participate in the group chat to facilitate discussion. Other researchers can access the messages without linking your response to your name.* *If you do NOT wish to participate, please reply "NO" to this message*	Jan 28
	Welcome to FarmChat. This is a chat of 5 maize farmers in Morogoro. You each learned from SoilDoc that you have a nitrogen deficiency in your soil. *Introduce yourselves, and use this chat to talk about improving the nitrogen content of your soil.* *You can ask questions, share experience, and talk about methods for improving*	Jan 31

	your soil that have or haven't worked for you.	
Make your soil healthy! Try intercropping maize with legumes, and using organic material from your farm to improve your soil. Plants need nutrients like nitrogen, which they get from the soil. When you remove the plant from the soil at harvest, you remove the nutrients too. You can replace nutrients by letting plant/animal materials decompose in your soil, or planting a legume. Then your soil will have nutrients to feed your next crop.	Have you noticed that your crop yield decreases if you use the same land year after year? Why do you think this happens? What do you normally do when you notice your land becoming less fertile?	Feb 1
Nitrogen is an important nutrient for growing maize. Legumes bring nitrogen from the air into the soil where it feeds crops. Try intercropping your maize with a legume. You will add nitrogen to the soil, reduce pests and diseases, and grow nutritious food for people and animals. Some good legume varieties include: - Pigeon pea - Beans - Ground nut - Cowpeas - Green gram - Soy beans	Think about your experience with legumes. Are maize plants healthier when they're grown alongside a legume?	Feb 4
Legumes are plants that absorb nutrients in the soil and help keep the soil moist. They absorb nutrients like nitrogen from the air and release them when cut. This helps increase the amount of nitrogen in your soil. If you plant them with maize, the maize can use the nitrogen to grow.	What varieties of legume have you experimented with? Do you plan to plant a legume this year? Why or why not? Which one? What kind of legume seeds are available in your local market?	Feb 5

	When is the best time to plant legumes? At the same time as maize? Or before or after? Do you plant your legume in the same row as maize, or a different row? How far apart do you put each plant?	Feb 8
Chicken manure is a great fertilizer. It has nitrogen and other nutrients. Keep chickens contained so you can collect their manure. Mix fresh and dry plant materials from your farm with manure, and let the mixture begin to decompose before adding to your field. This is called compost	Have you ever applied chicken manure as a fertilizer? Why or why not? Have you noticed an effect on your crop yields? When is the best time to apply chicken manure? At the same time as maize? Before maize is planted? After maize is planted?	Feb 9
	Do you keep your chickens contained, or let them roam free? What kind of structure or fence could you build to keep them contained?	Feb 10
Each year, maize takes nitrogen out of the soil, leaving less available for the next crop. Over time, your soil becomes unhealthy and it is hard to grow maize in it. If you replace the nitrogen by growing a legume and adding compost, your soil will stay healthy so you can keep growing maize for several years.	Have you noticed that the soil becomes less fertile after growing maize in the same place for a few years? Do you move your maize to a new plot when the soil becomes unhealthy? How often do you move it? Can you adopt practices to keep soil healthy longer? What techniques have you tried to improve your soil fertility? What techniques would you like to try this year? Next year?	Feb 11
Many farmers move their maize plot to new land when soil becomes infertile. If you do this, try growing legumes on the old plot. Then it will be ready to support maize the next year. Using compost and legume intercropping replaces the nutrients used up by maize,	Do you move your maize to a new plot when the soil becomes unhealthy? How often do you move your maize plot? Can you adopt practices to keep soil healthy longer?	Feb 12

and keeps your soil healthy year after year.		
	What techniques have you tried to improve your soil fertility? What techniques would you like to try this year? Next year?	Feb 15

Round 2 Extension Content[7]:	**Discussion Prompts:** *Messages in italics are sent only to chat-group participants*	**Date of Sending:**
	You have completed Part 1 of the SUA course about improving your soil. This month there will be another course, where you will receive information from SUA and be able to discuss it with the same group of farmers. *Your group is 5 maize farmers from other villages in Morogoro. You have all learned from SoilDoc that you have a nitrogen deficiency in your soil. The farmers in your group are all the same as last time.* *To chat with your group, simply reply to any SMS from us, and your message will automatically be sent to the 5 farmers in your group. If you receive a message from another farmer in your group, you can reply to it, and your message will be sent to the 5 farmers.* *Your message will automatically begin with the first 3 letters of your name, followed by ":". This is how you can*	5/14

[7] Some of the content for this round was taken directly from a Swahili pamphlet about green manures and compost. Since we sent the Swahili version to farmers, the version here is simply a translation for reference, made using Google Translate.

	easily tell which farmer in your group has sent the message you are reading. *When you send a message, the other farmers will see the first 3 letters of your name in front. For example, if your name is Mohammed, your messages will start with "Moh:". You do not have to type this yourself, the phone will add it automatically.* *Please use this chat to get to know each other, and talk about your farming practices and your soil. You can ask each other questions, and share advice about practices that you have tried or heard about.* *You can ask questions to the other farmers in your group, but please be aware that the agent from SUA cannot answer your questions, only the other farmers. This is for you to share advice with each other about what works for you. You will receive expert advice from SUA but cannot ask us specific questions through FarmChat.* *You have unlimited messaging paid for on your phone, so please chat as much as you want. This way you can meet other maize farmers who also have a soil nitrogen deficiency that was detected by the SoilDoc test. Together you can talk about ways of improving your soil and your yields.* *Please begin by introducing yourself to the other farmers in your group. Thank you!*	
Hello, this month you will receive messages from SUA about how to plant green manure and make compost for your farm. Thank you!	Have you tried growing a green manure crop this year or in the past? Which one did you grow?	17

Green manure is a plant that is grown for the purpose of increasing the level of organic matter and making food for soil microbes. These are fertilizers grown in the field.	Do you know anyone who planted green manure?	
This year has been very dry in Morogoro. Green manure crops help keep moisture in the soil, and can survive with little water. This year has been very dry in Morogoro. Green manure crops help keep moisture in the soil, and can survive with little water.		5/18
If green manure is cut before or during flowering, it is fermented easily with soil microbes - within two weeks of being moist and warm - after being buried in the soil.		5/19
Instead of digging green manure into the soil, it can also be distributed and act as mulch, especially if planted with perennial crops. Green manure crops produce lots of foliage that you can add to your compost or use as a mulch directly on top of your soil.	Have you ever considered mixing green leaves in topsoil? How have you seen green manure used by farmers you know?	5/20
Green manure can be incorporated into an existing agricultural system. No additional land is required to plant fertilizer Planting green manure as part of the crop cycle is very helpful especially if planted before crops that need a lot of nutrients.	Have you noticed that soil becomes dry and infertile when it is left bare? Planting green manure can keep your soil healthy and moist, and add nutrients which can be used by the next crop like maize.	5/21

Green manure is planted whenever there is no crop in the field, instead leaving the soil empty and allowing weeds to thrive and nutrients to be lost to the soil. It is also cultivated as a crop to break the cycle between species of similar crops for pest and disease control.		
Green manure can be grown between crop lines such as maize, sorghum and millet. To reduce competition with the main crop, green manure is planted if the main crop is already in good condition. Planting is sometimes mixed and green manure continues to thrive during the dry season.	Do you have space between rows of maize on your maize plot? Can you plant a green manure crop in this space?	5/27
Compost is essential for the soil's ability to retain nutrients and provide nutrients to plants when needed. Anything of plant or animal origin when put on the ground decomposes and turns to some extent into clay or compost. Creating compost is a long process. But investing in compost has great benefits for the plant and feed production.	Do you know anyone who makes compost? Have you ever seen a compost pile on someone's farm?	5/31
Compost is more than fertilizer, it creates soil. Its greatest value lies in its long term benefits to soil fertility. Compost is a highly valuable soil supplement for smallholder farmers who do not have access to natural or in-store fertilizers.	Can you use compost to keep your soil moist during a drought?	6/3

Compost has been proven to be the best type of organic fertilizer in drought-prone areas.		
Composting depends on the materials in the field and does not require special equipment, so it is a simple technique. But composting requires a lot of work to collect and prepare the material.	What types of organic material can you find around your farm? What can you add to your compost pile?	6/4
	Do you have time to make compost on your farm? Is making compost a valuable use of labor?	6/7
Making compost requires adequate equipment and materials and the right place. Compost is made from the same doses of animal manure and raw leaves and dried substances. Wood ash and old compost can also be included.	Can you find animal manure, raw leaves, wood ash, or other plant and animal materials to add to your compost pile? Which materials can you find on your farm or nearby?	6/9
The composting site should be close to the field, easily accessible and flat on the ground near a water source and adequate shade. If there is no natural shade, then a transfer shade is required. Making compost requires a humid environment. In dry weather, water is needed regularly to ensure proper process.		6/11
Making compost: 1.Chop the leaves of the plant to the size of a finger 2. Mix and add water to dry and green leaves separately 3. Mix different items by laying layers starting with the dried items 4. Place a metal rod on the pile and measure the temperature daily 5. When		6/15

the temperature drops in the pile, turn the pile up		
Making compost requires a lot of experience. But it also teaches you about many aspects of the natural processes of transforming organic matter into fertile soil.	Will you try making compost this year? Do you have any tips for other farmers who would like to try this?	6/16

Round 3 Extension Content:	**Discussion Prompts:** *Messages in italics are sent only to chat-group participants*	**Date of sending:**
Hello, welcome to the final course from SUA about improving your soil health with organic resources. You will receive information about managing crop residues and preparing your fields for the short rains growing season.	*Remember you are in a chat group with five other farmers who are also learning from SUA.* *You can chat with each other by replying to any message you receive here.* *You can tell that a message is from SUA if the SMS begins with "SUA:"* *A message is from another farmer if the SMS begins with the first 3 letters of a name, such as "Eli:" for Elizabeth.* *Use this chat to talk to each other about what practices you have tried, and what works or doesn't work on your farms. You can learn from each other and share knowledge this way.*	Aug 2
If you intercropped a legume with your maize crop, it should be ready to harvest before the maize.	Did you plant a legume on your maize plot this year? If so, which variety did you plant?	Aug 3

For smaller bean species you can easily pull out the plant and harvest the beans. After taking the bean crop, leave the entire legume plant on the field, including leaves, stems, and roots. This will act as a mulch for the maize and decompose easily into your soil.	Can you leave the legume crop residue on your field, or do you have other uses for this material?	
Make sure to save some beans and dry them to use as seeds for next year so you don't have to buy them again! Leaving the residue as a mulch will help preserve soil moisture and reduce topsoil erosion	Do you normally save seeds from each harvest to plant next season, or do you buy new seeds each year? Do you notice dry soil eroding from water and wind when it is exposed with no mulch or crop cover? How can you prevent this?	Aug 4
Maize is ready to harvest when a black layer is visible between the maize grain and the cob Try not to harvest maize before this stage, when it is still green, as this will make it harder to store and dry. Try not to wait too long after this stage, because the maize can begin to rot and is more likely to attract pests.	At what stage do you normally harvest your maize? What are the advantages of this? Can you see a black layer between the maize grain and the cob when it is ready to harvest?	Aug 5
You should not burn your maize crop residue (leaves, stems, roots, stover, and husks), because these are a valuable source of organic material which should be returned to the soil. There are two good options for managing your crop residue: 1) Composting, and 2) Leaving residue on the soil surface. We will discuss both of these options in detail when the course resumes on Monday.	Do you normally burn your crop residue? What uses do you have for maize crop residue on your farm?	Aug 6

1)Composting your maize residue: You can clear the residue off of the field at harvest, and add it to your compost pile. Cut the residue into smaller pieces to help it decompose faster. You should also add green materials, manure and water to your compost pile to help the decomposition. The compost will be ready to use on your field in a few months for the next year's long rains season.	Do you have a compost pile on your farm? If so, what do you add to your compost pile? Do you think making compost is a good way to use your maize crop residue? Why or why not?	Aug 9
Benefits of using residue for compost: mature compost is a great source of nutrients and microorganisms for your soil. Compost is easy to apply to your field and the nutrients are immediately accessible to your crops. Challenges: It will take several months for the compost to be mature and ready to use. It requires labor and knowledge to maintain your healthy compost pile.	Can you think of any other benefits or challenges of composting your maize crop residue?	Aug 10
2)Leaving maize residue on the soil surface: You can leave maize crop residue on the field after harvest. This will keep your soil covered and protected from sun and wind during the dry season. Pull out the plants and cut them up into a coarse mulch. The residue will decompose by the next long rains season. You can still plant maize or other crops during the short rains by clearing narrow rows or planting seeds directly into the soil under the residue.	Have you ever left maize crop residue on your field? Have you seen this practice on another farmer's field?	Aug 11

Benefits of leaving residue on soil surface: Leaving mulch will protect topsoil from eroding, and hold moisture in the soil by preventing runoff. Mulch will suppress weeds and prevent erosion, which can protect crops you plant during the short rains season. The decomposing residue will add organic matter and provide long term benefits to your soil health. This option is less labor intensive than making compost. Challenges: Leaving residue on the field can make it difficult to weed in the short term, and could make it more difficult to plant a cover crop during the short rains season.	Can you think of any other benefits or challenges of leaving your maize crop residue on your field? What will you do with your maize crop residue this year? Why?	Aug 12
Part 2: Preparing your field for the short rains season. When the rains are close, you can plant a short maturing legume crop on your plot This will keep the soil moist, add nitrogen to the soil, suppress weeds, and prevent erosion. It will also provide a nutritious food or animal fodder for your household, and green material to add to your compost or use as mulch next season.	What do you normally do with your maize plot during the short rains season? Do you think it's important to keep the soil on your field covered? What happens if you leave the soil exposed?	Aug 16
If you have left maize crop residue on the field, you can still plant a legume crop directly into the residue. Just clear a very small hole so you can see the ground and plant the seed. It will come up through the residue mulch. The residue will act as a mulch and protect the new crop.		Aug 17

Alternatively, you can clear narrow rows across your field and plant the new crop in these rows.		
When choosing a legume variety to plant during the short rains, there are a few things to keep in mind: The variety should be well adapted to your climate and soil, and tolerant to pests and diseases. The variety should grow fast and vigorously, and produce large quantities of leaves. It is good if the leaves are close to the ground so the crop forms a cover which will protect the soil from sun and wind, and help keep in moisture. The variety should be drought-tolerant and fast maturing.	What are some legume varieties that might be good to plant during the short rains? Why are these good options?	Aug 18
As soon as the rains start, you can plant some maize in the field as well. You can choose a short maturing maize variety, or plan to harvest green maize at the end of the short rains.	Do you normally plant maize during the short rains? Why or why not? Do you harvest green maize, or can you find a short maturing variety that is mature by the end of the season?	Aug 19
If you have successfully planted a legume crop already in the field, you can till or clear narrow strips where you will plant maize. Add the cleared legume plants to your compost pile, or use them as mulch around the new maize seedlings. The legume cover crop will protect the maize seedlings by providing shade and keeping moisture in the soil.	What are the benefits of intercropping maize and legumes? Will you try this practice during the short rains season this year? Why or why not?	Aug 20

It will also bring nitrogen from the air into the soil where it can be used by the maize crop.		
Thank you for participating in this SUA course! We hope you have learned some useful information about improving your soil health. There are lots of options for improving your soil. We hope you will discuss with other farmers about which practices work for you and which do not. Together we can innovate and improve our farming practices.	*Please continue to discuss with your chat group about practices you have tried or would like to learn more about!*	Aug 21

Appendix C: Survey Modules for Behavioral Outcome Variables

Knowledge:

A knowledge quiz appears in the survey as follows:

1. Which type of crop increases the nitrogen content of soil?

[ ] Grains
[ ] Vegetables
[ ] Legumes
[ ] Fruits

2. Which of the following crop varieties would supply nitrogen to maize plants when grown together in an intercropped field? *Select all that apply*

[ ] Soy beans
[ ] Groundnut
[ ] Sweet potato
[ ] Cowpeas
[ ] Beans
[ ] Tomato
[ ] Pigeon pea
[ ] Millet

3. What is the best way to plant maize seeds?

[ ] Take a handful of seeds and scatter across the surface of the field
[ ] Make small holes 5 feet apart and plant one seed in each hole
[ ] Scatter seeds along rows
[ ] Make small holes 8 inches apart along rows and plant 3 seeds in each hole

4. Which of the following are ways of improving the soil fertility on your maize plot? *Select all that apply*

[ ] Apply inorganic fertilizer
[ ] Apply compost
[ ] Intercrop maize with a legume crop
[ ] Plant a legume crop on the plot during the short rains season
[ ] Burn the crop residue left on the field after harvest
[ ] Leave crop residue on the field after harvest

5. What is the best time to apply poultry* manure to your field? **Poultry includes chickens, ducks, turkeys, and other domesticated birds*

[ ] 3 months before planting
[ ] 2-3 weeks before planting
[ ] At planting
[ ] When plants are 2 inches high
[ ] When plants are 6 inches high
[ ] After harvest

Questions 1 and 5 have one correct answer, and a total of one possible point each allocated to the total knowledge score. Questions 2 and 4 have multiple correct answers, and respondents receive one point for each correct selection, and lose one point for each incorrect selection, for a total of 5 possible points each. It is also possible to lose up to 3 points for question 2, and 1 point for question 4. Therefore, the final knowledge score takes a value between -4 and 12, inclusive. Question 3 is omitted from the knowledge score because it does not address a practice covered in the extension course. We use question 3 as a placebo to compare learning outcomes for targeted practices to general learning patterns.

Generalized PSE:

The items appear on the survey as follows:

- I will be able to achieve most of the agricultural goals that I set for myself
- When facing difficult tasks on my farm, I am certain that I will accomplish them
- In general, I think that I can obtain outcomes on my farm that are important to me
- I believe I can succeed at improving my soil and increasing the yields from my farm if I set my mind to it
- I will be able to successfully overcome many challenges on my farm
- I am confident that I can perform many different tasks on my farm
- Compared to other people, I can do most farming tasks very well
- Even when things are tough, I can make sure that my crops get adequate yields

This is adapted to the domain of agriculture from the validated New Generalized Self-Efficacy Scale (Chen et al., 2001):

- I will be able to achieve most of the goals that I set for myself
- When facing difficult tasks, I am certain that I will accomplish them
- In general, I think that I can obtain outcomes that are important to me
- I believe I can succeed at most any endeavor to which I set my mind
- I will be able to successfully overcome many challenges
- I am confident that I can perform effectively on many different tasks
- Compared to other people, I can do most tasks very well
- Even when things are tough, I can perform quite well

Domain-Specific PSE:

The module for eliciting task- and outcome-specific PSE for the domain of intercropping appears on the survey as follows:

> Many farmers and researchers around the world are promoting the practice of legume-maize intercropping, in which maize is planted in the same field as a legume crop such as pigeon pea. Growing pigeon pea provides a source of nutritious and valuable food. Pigeon pea, like all

legumes, also improves the soil fertility by providing nitrogen, which is an important nutrient for maize crops. Pigeon pea plants produce a lot of vegetation, which can be left on the ground as mulch to keep the soil moist and replenish nutrients as they decompose. To intercrop successfully, the farmer should plant seeds in evenly spaced holes along furrowed rows, with maize planted along the ridges and pigeon peas in the furrow. Poultry manure may be added to the ridges 2-3 weeks before planting, to provide additional nutrients to maize plants. Researchers say that intercropping, along with application of poultry manure, provides higher economic returns to farmers, by increasing the value of their product and reducing their costs. http://www.fao.org/3/a-i5310e.pdf

Now think about yourself and your own maize plot. Consider your abilities, any past experience you have with intercropping on your farm, and times you have observed these practices on someone else's farm.

1. On a scale from 1 – 5, where 1 is strongly disagree, 3 is neither agree nor disagree, and 5 is strongly agree, how much do you agree with the following statements:

If I decide to try the practices of intercropping and applying poultry manure on my farm, I will be able to:

a. … improve the soil fertility on my maize plot _____

b. … improve the profitability of my maize production ____

c. … increase my household's food security ____

2. For each component of the intercropping system (Building furrowed ridges; seed spacing; intercropping with pigeon peas; application of poultry manure), rate how difficult it would be to adopt this practice on your own main maize plot (1 = n/a I already use this practice on my own farm, 2 = Not at all difficult, 3 = Somewhat difficult, 4 = Difficult, 5 = Extremely difficult)

a. Building furrowed ridges
b. Seed spacing
c. Intercropping with pigeon peas
d. Application of poultry manure