Peer learning and technology adoption in a digital farmer-to-farmer network
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Violet Lasdun† Aurélie Harou‡ Chris Magomba§ Davíd Guereña¶

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Abstract

Information constraints rank high among barriers to agricultural technology adoption among small-scale farmers, particularly for complex bundles of complementary practices. Information communication technologies 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. In this study, we develop a low-cost digital extension platform that facilitates peer-to-peer learning through SMS-based chat groups on basic feature phones. Using a randomized controlled trial, we evaluate its effectiveness in promoting the adoption of beneficial agricultural practices compared to a one-way SMS extension program. We measure strong positive effects of treatment on adoption of practices discussed in the chat groups, increasing intercropping and organic fertilizer production by 11-18 and 15 percentage points, respectively, suggesting that a simple group discussion forum can be a powerful addition to digital extension initiatives. However, chat group participation declined over the course of the study, underscoring the challenges of designing technological interventions that sustain user engagement.

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†London School of Economics

‡McGill University, corresponding author: aurelie.harou@mcgill.ca

§Sokoine University of Agriculture

¶Alliance of Bioversity, International Center for Tropical Agriculture

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1 Introduction

As mobile phones proliferate across the developing world, digital delivery of agricultural advice is positioned to play a transformative role in increasing agricultural productivity and improving livelihoods for smallholder farmers (Fabregas et al., 2019; Giulivi et al., 2022). An abundance of mobile agriculture services have emerged over the past decade, providing farmers with market price and extension information, crop health diagnostics, and linkages to buyers and input dealers (Jensen, 2007; Fernando, 2021; Casaburi et al, 2019; Beverly and Thakur, 2021; Aker et al., 2016). Logistical constraints to in-person extension delivery suggest potential for mobile phones in getting information to farmers, and phone ownership substantially reduces information costs and asymmetries for rural households (Aker, 2011; Cole and Fernando, 2021). However, there is limited and mixed evidence of the effectiveness of mobile extension services, and the range of findings suggests that the impacts of individual initiatives are, in part, driven by specific design elements that determine whether the information provided will succeed in engaging farmers and changing behavior (Aker, 2011; Baumüller, 2018; Cole and Fernando, 2020; Nakasone et al., 2014, Steinke et al., 2021).

Information constraints rank high among barriers to adoption for smallholder farmers, particularly for complex bundles of complementary practices involving many components and various context-dependent methods for implementation. These practices, including integrated soil fertility management, integrated pest management and regenerative agriculture, are seen as important strategies for sustainably increasing agricultural productivity. In-person extension strategies that emphasize communication between various stakeholders have been successful in promoting their adoption (Barerra et al., 2005, Lunn-Rockcliffe et al., 2020, Saginga et al., 2009). Farmer-to-farmer extension (F2FE) in particular has been able to exploit 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; Nakano et al., 2018; Munshi, 2004; Beaman and Dillon, 2018). Similarly, participatory methods have become standard across many domains of agricultural development, engaging farmers and scientists in a process of knowledge co-creation leading to salient and actionable insights (Cash et al., 2003; Fadda et al., 2020; Larochelle et al., 2019; Olanya et al., 2010). Iterative communication between stakeholders is key to the widespread success of these approaches.

As interest in and potential for mobile extension rises, the social networking capacity associated with information communication technologies (ICTs) makes digital F2FE an alluring prospect. However, while ICTs overcome many of the logistical barriers associated with in-person extension, there exists little empirical research into whether users of a digital network engage with information in a way that leads to adoption. In this study, we develop a low-cost digital extension platform, ShambaChat, to enable discussion of extension information with a network of peers via SMS chat groups – a novel functionality for non-smart phones. We evaluate the impact of chat group participation on adoption of regenerative soil fertility management practices using a randomized controlled trial (RCT) among smallholder maize farmers in Morogoro, Tanzania. All study participants receive SMS broadcasts from a well-known local extension provider, the Sokoine University of Agriculture (SUA), about the targeted practices, while treated households are *additionally* placed in a 5-person chat group where they can freely discuss the information. Thus, our treatment consists of access to a peer discussion forum, and we are interested in measuring the added value of this interactive feature to support and strengthen a digital extension initiative. We also assess the design of the extension tool to understand a) whether the information is presented in a way that engages and sustains users over time, and b) the mechanisms by which participation in the group chat extension group might lead to adoption of the practices discussed.

We measure a large positive impact of treatment on adoption of practices that are actively discussed when farmers engage with each other through the platform. Legume intercropping was the practice most frequently discussed by farmers on ShambaChat, and we find that treated farmers were 18 percentage points more likely to intercrop maize with a legume relative to households in the control group (statistically significant at the 1% level), and 15 percentage points more likely to make organic fertilizer using materials found or produced on-farm (statistically significant at the 5% level). We also find a strong spillover effect to control farmers in treatment villages, suggesting the increased interest in the promoted practices may have reverberated through local social networks. Information coming from peers may be particularly effective in changing behavior, for example if observing the success or effort of a relatable peer raises the salience of extension content or increases one's own confidence in her ability to act, or through mechanisms such as social pressure, mimicry, and social learning. Additionally, the ability to engage in conversational back-and-forth discourse allows participants in a discussion forum to dive deeper into each practice, asking questions about the specific ways their peers have implemented general suggestions – for example, many farmers used the group chats to discuss which legume varieties they used for intercropping, where they could find seeds for them in local markets, and when they should be planted in relation to maize. We further discuss the possible mechanisms driving our results and highlight interesting avenues for future research in Section 6 below.

Despite these large adoption effects for chat group members, we find that activity in the groups decreases substantially with each subsequent round of extension. The drop in activity is accompanied by null treatment effects on practices addressed in later rounds, which is intuitive given that there was effectively no treatment occurring at this point - the treatment group had access to the chat groups but was not using them. While this reinforces our finding that active peer-group discussion is associated with increased adoption outcomes, it also highlights a serious design challenge for digital tools to engage farmers and maintain participation. We discuss these findings and their implications for the design of mobile extension tools that seek to capture the dynamics of farmer-to-farmer extension under current and future scenarios for digital communications technologies in developing country contexts. This study contributes to the emerging 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, Larochelle et al., 2019; 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; 2019; Casaburi et al., 2019), or market information services (MIS) that provide price information (e.g., Fafchamps and Minton, 2012). ICTs that enable multi-directional farmer-to-farmer communication exist, but are predominantly internet-based and require a smartphone or computer, precluding access for smallholder farmers in much of the world. 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 – in either a developed or developing country context – thereby contributing initial insights into the efficacy of a largely unexplored practice for digital extension programs. If digital peer discussion groups can significantly enhance the ability of an extension program to engender adoption, the potential impact is far-reaching. This is a low-cost feature that can be easily adapted to fit with any kind of digital (or in-person) learning initiative, following an established practice in many educational contexts (Brookfield and Preskill, 2012; Onyema et al., 2019).

Beyond our evaluative contribution, this study also makes a qualitative contribution to the literature on cognitive channels for behavior change in the context of agricultural technology adoption and ICT extension. We explore the mechanisms through which peer-to-peer discussion might increase adoption relative to a one-way SMS extension course, contributing to the prolific literature on the effectiveness of extension information (Abay et al., 2017; Conley and Udry, 2010; Cash et al., 2003, Kondylis et al., 2017; Beaman and Dillon, 2018; Maertens et al., 2020; Malacarne 2018; 2019; McGinty et al., 2008; Nourani, 2019; Spencer et al., 2018, Taffesse and Tadesse, 2017; Ung et al., 2016). F2FE that initiates dialogue between farmers in existing or newly established social networks can make information accessible by situating it in the experience of a relatable peer and providing evidence of yield and profit outcomes (BenYishay and Mobarak, 2018; Beaman and Dillon, 2018; Conley and Udry, 2010; Magnan et al. 2015). However, the conditions under which F2FE leads to adoption and the extent to which peer learning happens through social networks are not fully understood. Additional confounding factors come into play in the context of ICT interventions, such as difficulty reading and writing text messages on basic phones with alphanumeric keypads, maintaining sufficient airtime or battery charge, and low digital literacy (Aker et al., 2016; Steinfield et al., 2015; Wyche and Steinfield, 2016). We contribute to this literature by asking whether the conditions for successful F2FE are met in a simple SMS group discussion forum.

The remain of this paper is organized as follows. Section 2 reviews relevant contextual background for the study. Section 3 describes the study design and the intervention, while section 4 describes the empirical strategy. Section 5 presents our results which are discussed in Section 6. Section 7 concludes.

2 Background

We survey farming households across Morogoro Rural, one of six wilayas, or districts, in the Morogoro region of Tanzania. 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).

Soil nutrient deficiencies are a key constraint on agricultural productivity in SSA (Jama, 2008; Mutuku et al., 2020; Sanchez, 2002; Snapp, 1998), particularly in smallholder systems which are often located on marginalized or degraded lands (Jayne et al., 2014). 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). On average, nitrogen fertilizer application in SSA hovers around 9kg N per ha per year, while most staple crops draw at least 60kg N per ha per year from the soil (Jama, 2008, Myaka et al., 2006; Place et al., 2003). 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).

Integrated soil fertility management (ISFM) and regenerative agriculture (RA) practices provide an avenue to combat soil nutrient deficiencies at little financial cost to farmers by maximizing the use of on-farm resources (Al-Kaisi and Lal, 2020; Lal, 2020; Montgomery, 2017; Sanginga and Woomer, 2009). For example, intercropping legumes can replace much or all of the nitrogen consumed by maize and other staple crops through biological nitrogen fixation, reducing or eliminating the need for inorganic N fertilizer inputs (Adu-Gyamfi et al., 2007; Myaka et al., 2006; Rusinamhodzi et al., 2012). Deep-rooted legume varietals also pull water and nutrients from below ground, making them accessible to maize and helping prevent drought and erosion (Adu-Gyamfi et al., 2007). Furthermore, when legume residues decompose, their nutrients are released into the soil and made available for the next cropping cycle. The benefits of legume intercropping extend beyond agronomic ones, 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). In fact, Mutenje et al. (2019) find that combinations of climate-smart agriculture practices including legume intercropping had a net present value between $468 - $1,665 USD per ha in low potential agriculture zones in Malawi - suggesting significant economic benefits from adoption.

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). 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). While ISFM and RA practices require reduced input purchases, they may require additional labor. Furthermore, their proper implementation may be equally or more prone to information constraints. 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).

3 Study Design

3.1 Data

The sampling frame for this paper is derived from a prior experiment conducted between 2014-2019 across 47 villages randomly selected out of 214 villages in Morogoro, Tanzania, that were accessible by vehicle and known to grow maize (Harou et al., 2022; Tamim et al., 2024). In the previous experiment, participating farmers completed an endline survey in 2019. For the present study, we used cellphone numbers collected during that 2019 endline survey to contact households and conduct a baseline survey in 2020. From that sampling frame, we randomly assigned 37 of the 47 villages into a new treatment group and the remaining 10 villages into a control group[1]. Of the 733 available cellphone numbers collected in 2019, we were able to reach a total of 484 households at baseline in 2020, after making repeated attempts to reach them by the listed phone numbers as well as through village networks in case phone numbers had changed. Because our sample was restricted to farmers who had access to a cell phone and - in most cases - retained the same phone number over a year, our sample is no longer representative of the entire population. Nonetheless, it offers a realistic sample through which to explore the effects of a digital extension platform. Of these 484 contacted households, 468 (97%) agreed to participate in the extension program. From each participating household, we selected the household member who is most often responsible for making decisions about maize cultivation - this person was the household head in 88% of cases, the spouse of the household head in 11%, and the sibling or child of the household head in the remaining 1%.

The baseline survey was conducted in two 30-minute phone interviews with each household, in an effort to be less demanding on respondents in terms of time and attention. The first survey round included questions on asset ownership, housing and dwelling characteristics, patterns of food consumption, off-farm income sources, and market access and prices, as well as respondents' perceptions and attitudes towards the ongoing COVID-19 pandemic for use in a different study (Lasdun et al., 2023). The second survey round focused on agricultural production and climatic factors affecting production in 2020, and collected baseline levels of most variables of interest for this study including adoption of regenerative agriculture practices, an overview of all crops planted and inputs used, access to extension information and digital tools, experience of shocks, and self-reported yields. The corresponding endline survey was also conducted by phone, in one session, after the maize harvest and concurrent

[1] The prior experiment included two treatment arms – a voucher to purchase fertilizers and recommendations on fertilizers based on soil tests. The fertilizer initiative succeeded in increasing input use and maize yields among treated households in 2016, but with no significant remaining effect detected in 2019 (Tamim et al., 2024). The fertilizer initiative did not include any digital extension component, and therefore is unlikely to have influenced participants' level of experience sending or receiving extension messages - the object of the present study.

extension intervention was complete in August 2021. Out of the 468 households surveyed at baseline and included in the study, we were only able to reach 369, or 78.8%, at endline. This represents an attrition rate of 21.2%[2], and could result in biased estimates if participants do not drop out of the study at random. After describing the experiment below, we verify and confirm that attrition was indeed random.

3.2 The ShambaChat Extension Platform

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 to the cellphones of participating farmers. Additionally, it enabled us to group participants into 5-person chat groups where they could respond to our extension messages and discuss the content freely over SMS. Each extension broadcast was limited to 150 characters, and numbered to limit confusion if messages were received out of order. 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. 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. This allowed for clear identification of senders while ensuring their privacy as phone numbers were replaced by the three-letter nametag. To build trust and establish a relationship between members of chat groups, we began each month of extension with icebreakers and introductions.

3.3 Treatment Arms

The goal of this study is to assess the specific impact of augmenting SMS extension delivery with a chat group feature, and for this reason we chose to broadcast the same extension content by SMS to all study participants. This study design identifies the additional effect of participating in a chat group (the treatment) over and above the effect of the one-way SMS messaging campaign (received by all participants - treatment and control). However, it does not disentangle the effect of the SMS messaging campaign from time trends affecting adoption generally in the population, because all participants in the study received this - we leave the question of the efficacy of one-way SMS extension aside, referring readers to the existing body of literature on this topic (e.g., Acker et al., 2016; Baumüller, 2018; Casaburi et al., 2014; Fafchamps and Minten, 2012; Larochelle et al., 2017; Nakasone et al., 2014, Nyarko et al., 2013). 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 combined ShambaChat package

[2]Recent changes in Tanzanian laws regarding SIM card registration likely contributed to the high rate of attrition between 2020 and 2021. In May 2019 a new law required Tanzanians to biometrically register their SIM card (Beatrice, 2020). In the years following, many individuals adjusted to the new law, resulting in high turnover of cellphone numbers. Even without the upheaval of a new law, it is well-documented that cellphones and SIM cards in developing countries are often shared among household members or switched out, frequently changing an individuals' phone number (Aker et al., 2016; Steinfield et al., 2015).

(SMS message campaign + chat group feature) relative to no intervention.

Of the 47 villages, we randomly assigned 37 treatment villages and 10 control villages in order to examine potential spillover effects – discussed in Section 5.3. In treatment villages, we randomly assigned each household as either treatment or control. The chat groups were formed across villages so the groups were composed of 5 respondents each from different treatment villages, therefore unlikely to know each other prior. The choice of chat group size was guided by the finding from educational theory that participation is generally higher, and communication is of higher quality, in smaller discussion groups (Brookfield and Preskill, 2012; Lowry et al., 2006; Onyema et al., 2019; Pollack et al., 2011).[3] 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. We used farmer responses at baseline to identify all farmers who planted legumes in 2020 (hereafter, criteria F1, met by 32% of respondents) and used a soil conservation practice in 2020 (grass strips, ridges, bench terraces, drainage channels, water catchment, manure, compost or other) (hereafter, criteria F2, met by 34% of respondents). Chat groups were formed with one each of F1 and F2, and three randomly assigned members. We then allocated the chat groups randomly to treatment or control, for a total of 233 (50%) treated households, 158 (34%) control households in treated villages, and 77 (16%) households in pure control villages. Chat groups assigned to control were dissolved, as only treated farmers would be participating in these groups during the study. Figure 1 summarizes the study design.

3.4 SMS Extension Course

Given the prevalence of nutrient deficient soils in our sample, we selected a bundle of regenerative soil fertility management practices that promote soil health through enhanced biological processes and ecosystem dynamics. These practices substitute knowledge for input intensity, overcoming some of the constraints associated with promoting uptake of agricultural inputs like inorganic fertilizers, e.g., financial constraints. We developed a course on soil building, focusing on legume-maize intercropping green manure, poultry manure, composting, and integration of crop residues. We looked at production practices at baseline to inform the content of the extension course, aiming to target beneficial practices which were already used by a significant portion of participating households. The course was delivered in 3 parts, each lasting one month, during which all participants received 3-5 messages per day. 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 encouraged farmers to think more deeply about the information and relate it to their own experience or knowledge of similar practices[4]. The course, including discussion prompts, was delivered by SMS to both treated 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

[3] We did not have a large enough sample size to do so, but an interesting avenue for future work is to test the degree to which groups size and composition affects knowledge, adoption and behavioral outcomes.

[4] All messages by round are shown in Appendix A.

unlimited texting for the duration of the study period for all households, both treated and control. Figure 2 shows the timeline of events.

3.5 Attrition

Following Haushofer and Shapiro (2016), we test that attrition is not correlated with treatment by estimating the following equation using OLS, clustering standard errors 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 for control households in pure control villages (the omitted category), $k = 1$ for control households in treatment villages, and $k = 2$ for treated households. As seen in Panel A of Table 4, attrition is not correlated with treatment assignment, as treated and control households attrit at rates that are not statistically different. As an additional check, we verify that neither household demographic nor outcome variables are correlated with attrition by regressing each variable on the binary variable attrition as defined in equation (1) above. We estimate the following equation using OLS, with standard errors clustered at the village level:

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

Again, we find that attrition is not correlated with any baseline levels of household demographic or outcome variables, seen in Appendix B, Table A4.

The decision to plant maize occurred before the beginning of treatment, so there should be no effect of treatment on this decision, but nevertheless we test whether planting maize was correlated with treatment by running Equation (1), replacing *attrition* with a dummy variable indicating whether the respondent grew maize, and find no statistically significant relationship (shown in Panel A, Table 4).

Along with attrition, an additional 112 households did not plant maize in both survey years (59 in 2020, and 72 in 2021), and are therefore excluded from the main analysis. Given that our adoption outcomes of interest were practices to improve maize cultivation, we did not measure their uptake if respondents did not grow maize in both years. We therefore present our results restricted to the sample for which we have complete data - the 257 respondents who planted maize in both years. Households who did not plant maize in both years are not correlated with treatment (Table 4, Panel A, ”Planted Maize”).

3.6 Balance of Variables at Baseline

We verify that all relevant household demographics and outcome variables are balanced at baseline between treatment and control groups. To do this, we regress baseline levels of outcome and demographic variables on a treatment indicator using OLS where standard errors are clustered at the village level:

$$y_i = \alpha_0 + \theta_1 TREAT_i + \epsilon_i \tag{3}$$

where the treatment indicator $TREAT_i$ is equal to one for treated households and zero for all control households. We see that randomization into treatment is fairly balanced, with only two variables statistically significantly different from each other - *Other Legume Practices* and *Knowledge Score*. Table 1 Panel A shows the results of Equation 3 for the 257 respondents who grew maize in both years, since our subsequent analysis focuses on this group of farmers. For robustness, we also test the balance across the entire sample and similarly find the same two variables are imbalanced (see Appendix C, Table A5 Panel A). We later check the balance between control farmers in treatment villages and pure control farmers when examining spillover effects, see section 5.4.

4 Empirical Strategy

We are interested in understanding the effect of adding a chat group discussion feature to an SMS messaging campaign on participants' engagement with extension information. We estimate the effect of this treatment on adoption and behavioral outcomes relative to one-way SMS extension. We follow an intent-to-treat (ITT) analysis, where the independent variable is always the randomly allocated treatment indicator. More specifically, we measure the treatment effect using the following first differences equation estimated by ordinary least squares (OLS):

$$\Delta y_{ij} = \alpha_0 + \beta_j TREAT_i + \mathbf{X'} + \epsilon_i \tag{4}$$

where Δy_i are the difference in each of j outcome variables measured at endline (2021) and baseline (2020), described below, $TREAT_i$ is an indicator of treatment (one for treated households; zero otherwise), ϵ_i is an error term, X' represents the unbalanced variables found in Table 1 Panel A, 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. We calculate and report false discovery rate q-values (in square brackets) to adjust for testing multiple hypotheses, i.e., the likelihood of choosing one false discovery among a family of comparisons, using the method outlined in Anderson (2008). Standard errors are clustered at the village level to account for potential correlation of outcomes within villages. We cluster at the village level because of the sampling design – villages were first randomly assigned, and then households were randomly assigned within villages (Abadie et al 2022).

Because 53% of participants in the treatment group never actively participated in the chat groups (i.e., never sent a message to their group), it is difficult to say whether and to what extent they benefited from the treatment. The average number of texts exchanged per group (excluding texts sent by SUA) was 18, 4, and 7 in rounds 1, 2 and 3, respectively. Among active groups where at least one farmer participated (45 groups out of 53), the average number of messages per round were 21, 5, and 8. We therefore also estimate the effect of treatment on the treated (TOT), where we define treated groups as having at least one farmer who texted. We instrument this variable with the randomly allocated treatment variable to reduce the potential resulting bias. Since untreated households necessarily have a group message count of zero, there is a strong correlation between treatment and group message count, indicated by a Pearson correlation coefficient of 0.94, making this a valid instrument. Being randomly allocated, the treatment variable also meets the exclusion restriction for valid IVs.

We are mainly interested in measuring the effect of treatment on the adoption of soil fertility management practices, captured by a set of binary adoption indicators corresponding to the practices addressed through the extension course. To determine whether farmers adopted the practices described in the course, we asked whether they intercropped maize with legumes on their main maize plots, employed other legume practices such as cover cropping or crop rotation, planted a legume elsewhere on their farm (i.e. not on the main maize plot), collected organic materials from on farm (crop residue, leaf litter, food waste, manure), and allocated these materials as fertilizer. More specifically, the first variable, *Intercropping 1*, is based on respondents' answer to the question "Did you intercrop maize with a legume on your MMP this year?". The second intercropping indicator, *Intercropping 2*, 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). We include this measure to ensure that any effect we capture is not just the result of participants learning a new term for a practice they were already using, therefore it is the more conservative estimate of the two. The variable *Other Legume Practices* takes a value of one for respondents who used cover cropping or legume crop rotation. The variable *Legumes on Farm* takes a value of one for respondents who planted a legume anywhere on their farm. The variable *Organic Materials* is equal to one if the respondent produced any organic materials (maize crop residue, legume crop residue, manure, or leaf litter) on their farm. The variable *Made Organic Fertilizer* is equal to one if the respondent used on-farm organic materials found or produced on the farm to make organic fertilizer (compost). Finally, *Organic Fertilizer MMP* is equal to one if the respondent applied any organic materials (maize crop residue, legume crop residue, manure, compost, or forest soil) as fertilizer to their main maize plot.

5 Results

5.1 Summary Statistics

As a result of our decision to send extension content through ShambaChat to all study participants (treated and control), we are likely to see an impact on outcome variables across all households from 2020 to 2021. These year-effects are suggested by the statistically significant differences in key variables of interest between 2020 and 2021, shown in Table 1, Panel

B. Since we do not control for individual fixed-effects here, nor macro-level shocks occurring during the study period (for example, the COVID-19 pandemic), we do not attempt to attribute this effect to the intervention. Still, it is worth noting that 29% of maize-growing households intercropped maize with a legume on their main maize plot (MMP) after the intervention in 2021, compared to only 17% at baseline in 2020. Our second intercropping measure ensures that this effect is not entirely due to a change in the vocabulary used to describe the practice, as here we ask respondents to list the crops planted alongside maize on the main maize plot and set *Intercropping 2 = 1* if a legume crop is listed. By this more conservative measure, intercropping increases from 11% of the sample in 2020 to 20% in 2021. Interestingly, there is a 43 percentage point drop in the portion of farmers who report producing organic materials (crop residues and manure) on their farms, driven by a drop in crop residue production, and a corresponding decline in the portion who applied organic materials to the maize plot. This may, in part, be the result of lower harvests in 2020 leading to more limited access to organic materials, and poor climate conditions early 2021 leading to a decline in farmers planting maize and/or willingness to apply inputs to planted maize (USDA, 2022). The average knowledge score also increased by 1.9 points on a 16-point scale. These summary statistics are presented in Panel B of Table 1 for the 257 farmers who planted maize in both years.[5]

5.2 Uptake of the ShambaChat Platform

The ShambaChat SMS extension course was divided into three rounds, each lasting for one month and covering different (but overlapping) regenerative agriculture practices and agro-ecological principles. The course content and timing of information was tailored to the maize growing season in the study region, so that the relevant SMS would be received by farmers in time to discuss and take action (Cash et al., 2003; Larochelle et al., 2019). The first round focused on planting legumes alongside maize, and was sent out in the weeks before planting typically begins. The practice of making organic fertilizer (compost) from manure and crop residues was also introduced at the end of the first round. The second round provided more details on making organic fertilizer from materials found and produced on the farm, and was sent out during the middle of the maize season when farmers are less occupied by planting and harvesting activities. The third round focused on producing and processing crop residues to integrate into the maize plot soil after harvest. The course content disseminated by text are shown in Appendix A, Tables A1-A3, for each respective round.

For the treatment to be effective, participants need to actively use the group chat feature to discuss the practices from the SMS course. This is not straightforward, and many digital advisory services have failed to engage users due to a mismatch with farmers' interests and technological capabilities and use-patterns (Steinke et al., 2021). Indeed, use of the ShambaChat platform was not consistent throughout the study period or across topics, a reality that allows us to explore how active discussion on a given topic is related to specific behav-

[5] The summary statistics for the entire sample including farmers who did not plant maize in one or both years can be found in Appendix C, Table A5 Panel B, and are consistent with those shown here for the sub-sample of maize growers.

ior changes, but also underscores a serious design challenge to be overcome by practitioners seeking to integrate a digital peer discussion feature. We found that participation in the first round, which focused on legume-maize intercropping, was highest, with 952 messages sent by farmers in the chat groups (or 803 substantive messages excluding acknowledgement texts that only said "ok", "yes", or "thank you"). 378 (171 substantive messages) and 220 (79 substantive) messages were sent in rounds 2 and 3, respectively. The core innovation of the ShambaChat platform stands on its ability to increase the salience, or personal relevance, of agronomic information to farmers, thereby motivating action. To this end, the platform was designed to facilitate two-way, iterative, frequent, and sustained communication, encourage sharing of experiences and challenges, and for troubleshooting the logistics of engaging with an information communication technology (ICT). In Table 2, we present a breakdown of the message content and explore how the platform was used in ways that might increase the effectiveness of the extension communication.

We analyzed the content of the messages using simple natural language processing techniques in Python to gain an understanding of the ShambaChat user experience and communication process between farmers. 655 (or 69%) of the texts sent by farmers during the first round were direct responses to our extension broadcasts, while 341 (or 36%) of the texts were direct replies to another member of the chat group (some messages contained both), indicating that there was both active dialogue between members and direct engagement with the course material. 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. The discussions in the chat groups focused exclusively on agriculture, but sometimes veered off the topics presented in the SMS course. For example, 22 messages were sent about pest control options, suggesting that this would be a topic of interest to farmers in future courses. A potential issue arises if farmers share misinformation in the chat groups or contradict the content of the extension broadcasts, but we do not see much evidence of this occurring. In fact, 263 of the messages sent by farmers directly reinforced the extension content, while only 25 contradicted it. Only 9 messages contained objectively inaccurate information, while 100 messages explicitly expressed intent to try one of the targeted practices for the first time.

Farmers sent 378 messages about legumes, comprising 36% of all substantive messages sent throughout the study, and listed 14 varieties by name. 252 messages (or 24% of substantive messages) sent were about using organic materials from the farm to make fertilizer (compost). This is an indication that farmers were initially interested in the extension content and used the chat groups to deepen their engagement with the material by discussing it with their peers. Examples of each type of message can be found in Table 2. During the second round of the course, which focused on collecting on-farm organic materials for fertilizer, we saw a 60% (78%) decline in messages (substantive messages) in the chat groups relative to the first round - from 952 to 378 (803 to 171). The message content from farmers was limited, consisting of 45% introduction messages and thank you notes in response to extension broadcasts. 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. Only 220 (79) messages (substantive messages) were sent during the third round, a 76% (90%) decline relative to the first round. In effect, the treatment excluded practices covered in the third round, namely harvesting maize crop residues and the application of these organic materials to the maize plot.

5.3 Treatment Effects

We find a positive and statistically significant impact of group-chats on legume intercropping, shown in Table 3 Panel B (showing results from equation 4). Treated households were 17.7 percentage points (p-value = 0.009) (11.3 percentage points (p-value = 0.009)) more likely to plant a legume on their MMP in 2021 relative to control households in 2021 using the *Intercropping I* (*Intercropping 2*) measure. The two measures, *Intercropping 1* and *Intercropping 2*, differ slightly as some farmers may have planted a legume alongside maize without recognizing this practice to be intercropping, and part of the treatment effect captured by *Intercropping 1* could be explained by a shifting of terminology after being exposed to this term. We also find that treated households were 14.7 percentage points (p-value = 0.049) more likely to make organic fertilizer (compost) from the organic materials found and produced on farm. Given the sharp decline in organic material produced noted in Table 1 and Section 5.1 above, this suggests that of those who did produce organic materials such as crop residue and manure, treated participants were more likely to follow the extension advice and use those materials to make organic fertilizer.

There is no effect on *Organic Materials* or *Organic Fertilizer MMP*. We note that *Organic Materials* is a composite variable equal to one if a respondent found or produced maize crop residue, legume crop residue, manure, or fallen leaves and debris from forest or fruit trees. The variable is driven almost solely by production of maize crop residue, as fewer than 7% of respondents with *Organic Materials = 1* indicated any of the other materials. Similarly, *Organic Fertilizer MMP* is driven primarily by maize crop residues (indicated by 50% of respondents with *Organic Fertilizer MMP = 1*). Since these practices were both emphasized in the third treatment round, where chat group participation was minimal, our null findings are consistent with the view that active discussion about a given practice is a prerequisite for finding a treatment effect. Only 16 respondents (5.4% of the total sample) had *Organic Fertilizer MMP = 1* in 2021.

Our results are robust when estimating the aforementioned TOT, shown in columns 3 and 4 in Table 3. We find slightly higher coefficients on both intercropping measures, and on making organic fertilizer, which is to be expected given TOT looks explicitly at groups that were actively participating in the treatment.

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 them as well (Feder et al., 2004). To test for spillover effects, we estimate the following first-differences equation using OLS with robust standard errors clustered at the village level:

$$\Delta y_{ij} = \alpha_0 + \sum_{k=0}^{2} \theta_{kj} TREAT_i^k + \mathbf{X'} + \Delta\epsilon_i \tag{5}$$

where Δy_i is the difference between endline (2021) and baseline (2020) values of the outcome variables of interest, regressed on 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. X' represents the unbalanced variables discussed below. 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.

We test the balance between control households in treatment villages, and control households in pure control villages, as we did in equation (3) above but where we set $TREAT_i$ equal to one for control households in treatment villages, and zero for households in control villages. The results, shown in Appendix D, Table A6, show that several variables are unbalanced between the two control groups. Namely, *Land Owned* (difference statistically significant at the 5% level) and *Owned Main Maize Plot* (difference statistically significant at the 10% level), with control households in treated villages owning approximately double the amount of land as control households in control villages, and being 10 percentage points more likely to own their main maize plot. A concern arises if the control households in treated villages differ in important ways from those in pure control villages, for example if the fact that they own more land and are more likely to own their maize plot enables them to respond in a different way to the SMS extension course, perhaps finding the advice more actionable given their higher resource level. We therefore add these unbalanced variables to the vector of controls X'. However, they may point to underlying unobservable differences which could upwardly bias our estimates.

Nonetheless, results from estimating (5) suggest the presence of spillover effects, indicated by the significant θ_1 coefficient on the first and second legume intercropping measures and the indicator for making organic fertilizer in Table 4. Within the same social learning theory that underpins our main results, there is a strong explanation for potential spillovers as village members observe their treated neighbors adopting new practices. Unsurprisingly, the spillover effects are limited to the outcomes for which we find a treatment effect, suggesting that peer learning, whether face to face or through a digital networks, may increase uptake of new agricultural practices and receptivity to extension information. The presence of spillovers indicates that our ITT results may be under-reporting the true effect of the chat group feature.

5.5 Heterogeneous effects

We also test whether our results on intercropping are driven by any particular group by examining the differential treatment effect by gender, asset quintile, and underlying soil characteristics. We do this by running a regression of first differences on treatment, the variable of interest, and the interaction of the variable of interest with treatment. We do not find that our positive treatment effects are driven by any of these groups. The positive and statistically significant treatment effects hold, with the effect on *Intercropping 1* reported in the first row in Appendix E, Table A7.

5.6 Cost savings

Farmer-to-farmer extension programs are already touted for their cost-effectiveness relative to other extension methods, particularly those involving trained, salaried professionals to deliver information in-person. However, the costs of training lead farmers, covering their transportation, and in many cases providing additional stipends can be significant. Wellard et al. (2013) calculate costs per lead farmer between 127 – 790 GBP per year in a review of F2FE extension programs across Ghana, Uganda, and Malawi. The ShambaChat model by contrast does not require ongoing payments to trainers or transportation costs. The course content, once developed, can be re-used indefinitely. The only cost is hosting the network and covering texting costs. Such costs vary depending on the number of expected users, the average number of text messages sent, and the technology. We expect improvements in technology to lower future costs. For this study, we incurred monthly costs of $140 covering 257 farmers (in fact, the costs would have been the same with the full initial sample of 484 farmers). Thus, our monthly cost per farmer was $0.55, or $6.60 per year (or $0.29 ($3.50) per farmer per month (year) if we had the full sample). This includes costs of both treated and control farmers. Ideally we would like to compare the costs of treated farmers who can text each other to control farmers who received information via one-way texts. The starter pack at Telerivet currently costs $45 per month and allows one-way texting to 1000 contacts. We apply this cost to the number of farmers in our study, 256 (484), which would represent a cost of $0.18 ($0.09) per farmer per month or $2.11 ($1.12) per year. Thus, adding in-group texting triples the cost, but still represents large cost-savings relative to in-person F2FE. While in-person extension services, including those operating through lead farmers, experience fairly linear cost increases with additional farmers due to transportation and training expenses, the digital F2FE method significantly reduces costs per farmer as it scales up. Indeed, rough cost estimates provided by Telerivet for annual farmer costs in a similar program as the one we provided via ShambaChat were $1.44 for 1,000 farmers, $0.29 for 5,000 farmers, $0.16 for 50,000 farmers and $0.12 for 100,000 farmers.

6 Discussion

6.1 Summary

We find significant and positive treatment effects from chat group participation on adoption of intercropping practices, as measured by two indicators, *Intercropping 1*, and *Intercropping 2*. We also find a positive treatment effect on making organic fertilizers (*Made Organic Fertilizer*), significant at the 5% level, but no effect on producing organic materials on-farm (*Organic Materials*), or on applying organic materials to the maize plot (*Organic Fertilizer MMP*)[6]. The presence of spillover effects for these same adoption outcomes suggests that treatment also benefited untreated households through community networks, although we interpret these results with caution due to baseline imbalances between pure control villages and villages with some treated households. Our findings are consistent with others in the ICT-adoption literature. For example, Larochelle et. al. (2019) find that a follow-up text message led to a 5.5-9.3 percentage point increase in the adoption of integrated pest management practices. Kondylis et. al. (2017) find that an additional training for contact farms in an extension program in Mozambique increased the adoption of sustainable land management practices by 26-65 %, despite seeing little or no effect on knowledge levels.

The intensity of treatment effect for the various adoption outcomes coincides with the take-up and use of the ShambaChat chat group feature, suggesting that active discussion about a certain topic in the chats may have increased its adoption relative to a one-way SMS extension course. As conversation dropped off over time, the treatment effect decays on practices that were discussed in the later treatment rounds, namely applying organic materials to the maize plot (*Organic Fertilizer MMP*), and harvesting crop residues (the driver of our composite treatment indicator *Organic Materials*). The timing of messages and data collection may also explain the varying treatment effects across adoption outcomes. In particular, applying organic fertilizer to the main maize plot would require some progress on making organic fertilizer (compost), a practice that was only introduced half way through the three-month growing season, and we were not able to follow up with farmers about their fertilizer application in the following season. Additionally, treatment effects may vary due to the actionability of the different practices. For example, if producing more organic materials means acquiring livestock or changing one's herding practices to collect manure, or diverting crop residues away from other valuable uses such as livestock feed or building material, then these practices may be less actionable than planting legumes, with higher barriers to adoption (Berazneva et al., 2018).

In the following discussion, we present a theory of change for how participation in the chat group discussions may have led to the observed treatment effects on adoption. We address methodological limitations that may have impacted our results, including our challenges with measuring the behavioral mechanisms through which peer-to-peer discussion affects adoption choices, as well as broader limitations to the use of ICTs for farmer-to-farmer communication, and design considerations for future extension platforms.

[6] I.e., of those who did produce or collect organic materials on farm, the treated group was more likely to use those materials to make fertilizers like compost.

6.2 Potential for Social Learning in a Digital Discussion Group

Several studies have looked at the mechanisms through which F2FE promotes learning and adoption of agricultural practices, hoping to identify factors that influence the success of a given F2FE initiative (Fisher et al., 2018; Kondylis et al., 2017; Maertens et al., 2020; Nakano et al., 2018; Wellard et al., 2013). Maertens et al. (2020), and Nourani (2019) model technology adoption as a two-stage social learning process in which farmers first formulate their yield expectations for a given technology based on observed yields among early-adopting peers, and then make a decision about how much effort they will expend to learn and adopt the technique on their own farms. In this way, new agricultural practices spread from farmer to farmer as evidence of their benefits and profitability works its way through social networks and members update their subjective expectations associated with adoption. The authors identify factors that make certain F2FE approaches more likely to raise farmers' expectations about a new practice enough for them to allocate attention to learning and adopting it. Proximity is important, for example, because the returns to a given practice depend on soil and other environmental conditions, and farmers place more weight on benefits observed within their own agroecosystem or community. Foster and Rosenzweig (1995) observe this effect in rural India, where farmers with more experienced neighbors are found to have higher adoption rates of Green Revolution technologies and higher profits. Similarly, Conley and Udry (2010) observe that pineapple farmers in Ghana modify their input-use as they observe their neighbors' success with new technologies.

F2FE seems to work best when role models are relatable, in terms of socioeconomic status as well as agronomic know-how, and may be less effective if they are perceived as being too far ahead of their peers in terms of technology adoption (Wellard et al. 2013). Information situated within a personally relevant context has been shown to increase its motivational salience and engage the attention and processing capacity of recipients (Fisher et al., 2020). Indeed, BenYishay and Mobarak (2018) conduct an RCT in Malawi which compares the ability to communicate agricultural information effectively through (1) government extension workers, (2) trained 'lead farmers', or (3) untrained 'peer farmers' who are representative of the general population in terms of their characteristics and level of experience with the targeted practices. Peer farmers are found to be the most effective communicators, likely because they are perceived as relatable in terms of socio-economic status as well as agricultural conditions such as farm size and access to inputs. However, the authors find that technology diffusion does not happen unless peer farmers are incentivized to share information with their social networks.

The ease of social networking on digital platforms points to the suitability and potential of ICTs for F2FE, which is predicated on the ability to connect and communicate with others. Moreover, if technology adoption is promoted through observation of peers, there is clear potential for ICTs to foster communication linkages that spur adoption among members of a digital peer-to-peer extension network (Nakasone et al., 2014). Indeed, a number of agricultural networking websites and mobile platforms have emerged and gained popularity across SSA (e.g. FarmAfrica, WeFarm, M-Farm), providing targeted information and facilitating knowledge transfer among users, as well as connecting producers with local buyers and input sellers (Aker et al., 2016; Lunn-Rockcliffe et al., 2020; Leveau et al., 2019; Nakasone et al., 2014).

While the present study is the first we are aware of to evaluate the effect of a digital peer-to-peer ICT extension program on agricultural technology adoption, there is a well established literature on the use and efficacy of online discussion forums (ODFs) to enhance learning outcomes in other domains, to which we draw a tentative parallel (Bender, 2023; Caspi et al., 2008l; Krentler and Willis-Flurry, 2005; Onyema et al., 2019; Pena-Shaff and Nicholls, 2004). As with in-person peer-learning and interactive learning methods, ODFs facilitate participatory exchange of ideas among users, deeper engagement with the material, iterative problem solving, and critical thinking (Onyema et al., 2019; Pollack et al., 2011). It also provides a space for asking questions and identifying specific solutions that may not have been clear in the primary course content. Krentler and Willis-Flurry (2005) find a significant increase in GPA when high school students take part in an ODF, and Hamann et al. (2009) find an effect on course performance even for students who are part of an ODF but do not actively post, suggesting that just reading the content posted by peers translates to positive learning outcomes. Szabo and Schwarz (2011) find that access to an online discussion forum increased university students' score on the Ennis-Weir Test of Critical thinking. To the extent to which learning outcomes like these may predict or engender adoption outcomes, for example by reducing the information constraints surrounding new and potentially complex practices, or by building self-confidence and efficacy beliefs, these studies may provide some context for interpreting the results observed for participants of the ShambaChat digital discussion platform.

6.3 Mechanisms for Behavioral Change

Various mechanisms may have played a part in the large effects we observe on adoption for treated participants, either in a mediating role for social learning, or operating on other channels. We initially explored a potential connection between peer learning and perceived self-efficacy (PSE), whereby exposure to other farmers who have successfully adopted certain practices, combined with a space for generating context specific implementation methods for general practices, may increase personal efficacy beliefs, engendering adoption by reducing this psychological barrier to action (Abay et al., 2017; Malacarne 2018; 2019; McGinty et al., 2008; Taffesse and Tadesse, 2017; Ung et al., 2016). Several studies have demonstrated a connection between social-learning, self-efficacy beliefs, and technology adoption, see for example Bernard et al., 2005; Lybbert and Wydick, 2016; McGinty et al., 2008; and Ung et al., 2016). We elicited several measures of PSE in an attempt to identify this psychological impact channel, but unfortunately did not capture any change in participants' efficacy levels before and after the intervention. Nonetheless, we report our results and a short discussion of PSE in Appendix F. A similar explanation is that the ShambaChat platform may have improved adoption outcomes by increasing participants' motivational salience as they engage with extension information. Motivational salience is a cognitive process that translates from attention to action, and has been shown to increase when information is presented in a way that is personally relevant to recipients (Cash et al., 2003; Fischer et al., 2020; Spencer et al., 2018). Designing an experiment to measure salience as a mechanism to explain increased adoption is an interesting area for future research.

Additional mechanisms may sidestep social learning altogether. For example, Tjernstrom (2016) finds that farmers in a social network respond both to the information provided through the network (the social learning effect) and the number of people in the network who adopt, which she describes as a social pressure or mimicry effect. If treated individuals using the ShambaChat platform are exposed to more people they perceive as adopting or likely to adopt a new practice, they may respond by mimicking the adoption choice without truly learning (i.e., without updating their beliefs or knowledge about implementation of the practice itself). If social mimicry spurs adoption, learning-by-doing may ensue, wherein farmers update their beliefs about the returns to new practices as they gain experience with them (Foster and Rosenzweig, 1995). Further research is needed to measure expected returns before and after adoption and identify whether a change in expectations drives adoption (e.g. through social learning), or adoption drives a change in expectations (e.g. learning-by-doing).

A more problematic explanation is if respondents succumb to social desirability bias, i.e., choosing responses they believe are more socially acceptable in lieu of choosing ones that reflect their true thoughts. If participation in chat groups fostered the belief that the targeted practices were desirable and popular among other farmers in a social network, or that these are the practices one *should* be using, treated farmers may be more likely to falsely report adoption. Our results may also pick up a reference bias, if treated participants have had more reminders about the targeted practices throughout the season and are therefore more likely to remember and report them at endline. This cognitive bias engendered by continuous discussion of certain practices may result in different interpretation of the questions by treated respondents. Due to the COVID-19 pandemic we were not able to visit the farm sites in person to observe actual adoption, so we cannot rule out these biases. However, we capture adoption of intercropping in two variables (*Intercropping 1* and *Intercropping 2*) spaced out in the survey and not presented as an evaluation of performance. Given that we find significant treatment effects on both measures, including *Intercropping 2* which simply asked respondents to list the crops planted alongside maize and takes a value of one if a legume crop is listed, social desirability and other cognitive biases in response patterns are unlikely to explain the full effect. Other forms of measurement error may have also occurred. For example, if the phrasing of questions surrounding the various legume and organic materials practices were ambiguous, or if respondents do not provide accurate information over the phone. However, these are not likely to vary systematically with treatment, so we do not expect them to bias our estimates.

6.4 Limitations of Technology

Despite the demonstrated advantages of the ShambaChat platform for facilitating communication of extension information, it was still constrained by the technological limitations faced by other digital extension tools designed for contexts with low technological capacity and literacy. If the promotion of complex agriculture technologies like ISFM and RA have been difficult even for in-person F2FE initiatives, it is not surprising that we faced challenges translating them to a digital learning environment. Indeed, engaging with an online community, especially one composed of strangers, can be challenging, and made more difficult on non-smart phones, with participants who likely have varying degrees of technological literacy. In low-resource contexts there are additional well-documented challenges to ICT engagement. Basic feature-phones are not optimized for receiving long messages or typing detailed responses on an alpha-numeric keypad. Low-literacy users in particular may be more accustomed to using these phones only for voice messaging and calls, and less likely to benefit from information provided by text (Aker et al,. 2016; Steinfield et al., 2015). Low-income households may also struggle to maintain sufficient airtime funds or battery charge, and may not be able to fix or replace broken phones, leading to discontinuous use patterns. Also, phones and SIM cards are often shared among household members or switched out when they run out of airtime or for other reasons, so an individuals' phone number tends to change frequently (Aker et al., 2016; Lasdun et al., 2023; Steinfield et al., 2015). These technology barriers make it difficult for users to engage with information presented by SMS and may limit the potential of ICTs to overcome information constraints for rural households.

To gain insight into why certain farmers did not engage in the group chats, we surveyed 90 farmers from the treatment group after the first round of extension. The main reasons cited for not participating in Round 1 included being too busy to reply, being unable to reply because of broken technology, or not understanding 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).

7 Conclusion

By launching a low-cost, beta version of ShambaChat, a digital extension platform allowing farmers to text each other on basic feature phones, among a relatively small userbase, we were able to observe and discuss both its failures and successes, providing a relevant case study for practitioners considering the use of digital F2FE. The positive performance of the ShambaChat platform, particularly during the first round of extension, leaves us optimistic regarding the potential for digital F2FE, and supports further development of ICTs to facilitate connections between farmers. We saw active conversation between farmers surrounding the content of the course and measured a significant impact on adoption of the practices that were discussed, as well as spillover effects suggestive of further benefits through community networks. Farmer-to-farmer communication is a well-established mechanism for promoting agricultural technology adoption and learning, yet this feature is typically not present in digital extension programs. Inspired by the evidence of online discussion spaces as successful tools for engendering learning outcomes in other domains, our study assesses whether F2FE dynamics can be preserved in a digital space.

Providing extension through ShambaChat is low-cost and logistically straightforward relative to in-person F2FE, with costs per farmer decreasing substantially at higher scales. This makes evidence of its effectiveness highly relevant to policymakers and practitioners seeking ways to reach farmers and overcome information barriers. However, significant technological limitations need to be addressed by practitioners looking to add a discussion feature to digital extension programs. ShambaChat's failure to keep users engaged over multiple extension rounds highlights the need for future interventions to seek guidance from farmers about topics of interest, and tailor the extension tool to their specific goals and levels of technological literacy. Practitioners should consider adding features such as voice notes or calls, grouping participants within communities rather than with strangers, and ensuring users have sufficient airtime and resources to maintain their phones. Gamification of the platform may also incentivize users to share and engage with information. These design considerations are particularly important as smartphone penetration rises, making digital F2FE a viable and promising format for engaging farmers with agricultural innovations.

Finally, our study points to several avenues for future research in this domain. More work is needed to understand how group size and formation affect discussion and adoption, and whether certain groups of farmers engage with the technology differently. Additionally, further research should investigate the mechanisms driving increased adoption, including behavioral drivers like PSE and motivational salience, and distinguish adoption from mimicry, social desirability, or reference bias.

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Figure 1: Study Design

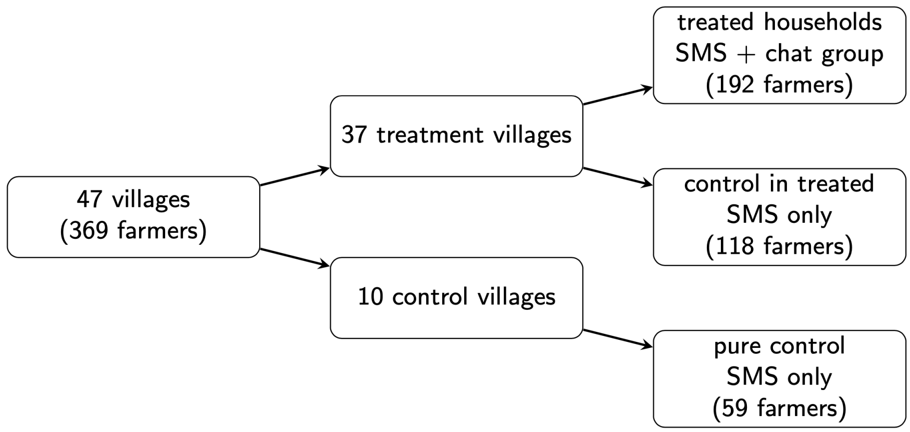
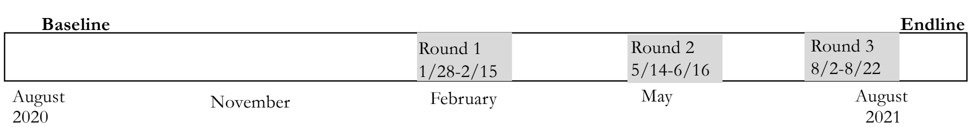


Figure 2: Timeline



Tables

Table 1: Baseline balance and summary statistics

Panel A: Baseline balance	Control (SMS only)			Treated (SMS + Group chat)			
	n	mean	std. dev.	n	mean	std. dev.	difference
Socioeconomic variables							
Age of respondent (years)	127	47.19	12.57	130	49.11	12.84	1.919
Gender of respondent (=1 if female)	127	0.31	0.47	130	0.25	0.44	-0.061
Education of respondent (years)	127	6.75	1.32	130	6.49	1.69	-0.25
Dependency Ratio	127	153.86	115.50	130	162.62	126.46	8.752
Food Insecurity in 2020	127	2.13	1.82	130	2.20	1.74	0.071
Land Owned, acres	127	7.62	9.58	130	6.41	7.43	-1.218
Owned Main Maize Plot	127	0.90	0.30	130	0.94	0.24	0.041
Asset Index	127	0.23	2.22	130	0.06	2.28	-0.168
Outcome variables							
Intercropping 1	127	0.19	0.39	130	0.15	0.35	-0.043
Intercropping 2	127	0.13	0.33	130	0.10	0.30	-0.026
Other Legume Practices	127	0.13	0.33	130	0.21	0.41	0.082*
Legumes on Farm	127	0.32	0.47	130	0.42	0.50	0.100
Produced Organic Materials	127	0.61	0.49	130	0.70	0.46	0.094
Made Organic Fertilizer	127	0.17	0.37	130	0.14	0.35	-0.027
Applied Organic Fertilizer	127	0.27	0.44	130	0.26	0.44	-0.006
Panel B: Summary statistics	2020			2021			
	n	mean	std. dev.	n	mean	std. dev.	difference
Outcome variables							
Intercrop w legume on MMP (1)	257	0.17	0.37	257	0.29	0.45	0.121***
Intercrop w legume on MMP (2)	257	0.11	0.32	257	0.20	0.40	0.089***
Other legume practices	257	0.17	0.37	257	0.11	0.32	−0.054*
Legumes on farm	257	0.37	0.48	257	0.37	0.48	−0.002
Produced organic materials	257	0.65	0.48	257	0.23	0.42	−0.428***
Made organic fertilizer on-farm	257	0.15	0.36	257	0.13	0.34	0.019
Applied organic fertilizer MMP	257	0.26	0.44	257	0.04	0.20	−0.222***

NOTES: Panel A shows the balance of baseline socio-economic and outcome variables among the 257 respondents who grew maize in both survey years, by regressing each baseline variable on the treatment indicator. The difference column shows the coefficient for this regression. Standard errors are robust and clustered at the village level. Education counts the respondent number of years of education (completing primary school is seven years). Food Insecurity is the household score based on the Food Insecurity Experience Scale (FIES), which ranges from 0 - 8 in increasing food insecurity. Owned Main Maize Plot is an indicator variable equal to one for households who owned their main maize plot during the 2021 growing season. Asset Index is an index calculated using principle component analysis of items owned by households at baseline including household, productive, and livestock assets. Panel B shows the results of t-tests comparing the mean of each outcome variable for the entire sample (treatment and control groups) between baseline (2020) and endline (2021). ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

Table 2: Message Content

	Round 1 Count	Round 2 Count	Round 3 Count	Examples
Message Content:				
Legumes	290	20	22	• "I will grow green gram and beans because they take a short time to be harvested" • "The kind of legume seeds available in my area are green gram, cowpea and pigeon pea"
Organic Materials	152	68	32	• "The best time to apply manure on maize plot is before planting" • "The method of making compost is to add plant and animal residue/material in the compost pile throughout the year. Also to add a mixture of green plant (wet) materials and dry plant materials to remove odour of the compost. But I have neither used nor seen it before. I am learning from SUA, I think it is a good use of labour."
Other Cropping Practices	100	2	7	• "On my farm, I plant by using a stick to make holes" • "There are pests that destroy maize by eating in the middle of the plant, they are white, these pests are holding back our economic development, what can we do to get rid of it?"
Message Type:				
Question	127	31	14	• "How many years should I plant legumes to get nitrogen in the farm?" • "What are the impacts of growing maize on the same plot for more than 5 years?" • "Suppose I plant legume varieties in order to make the farm fertile, for how long should they stay in that farm before planting maize in it?"
Advice	219	11	14	• "First I plant maize, then after seven days I plant legumes" • "The time of planting legumes is in February, and it is planted at the same time as maize" • "I plant both cowpeas and maize in one row" • "Maize becomes unhealthy, unless the seed holes are separated, i.e. the maize hole and the legume hole." • "You plant [legumes] together with maize or you can plant maize first and after two weeks you plant legumes."
Challenge	48	10	10	• "I don't burn the crop residues after harvest, but we face the challenge of cattle feeding on crop residues. For that reason you cannot find the maize stover on farm between August and September. I think even the decreased productivity/yield is contributed by cattle which affect the soil fertility of farm." • "There are practices we can use, for instance to leave the maize stovers and other crop residues to decompose on farm, but the problem is cattle feed on the residues." • "Chicken farming is good, a challenge is the cost of shed and animal heath cost to raise them."
Intro	70	1	3	• "I am a farmer, I like farming very much but the yields are low."
Logistic	64	8	11	• "Is there a special/specific time to chat with SUA?" • "My phone has problem in charging system and screen display."
Intent	52	35	13	• "The legume that am expecting to grow this year is cowpea. I grow cowpea to improve soil fertility in order to make Nitrogen available in the soil." • "Before planting maize I apply compost. I am expecting to grow legumes after harvesting maize. I will grow cowpea." • "My farm is less fertile, this year I will apply manure and I will plant maize, together with vegetable of legume type in order to increase my soil fertility."
Reinforce	213	32	18	• "It is true, fertility decreases when cultivating maize on the same field over years." • "Legumes are profitable, it provides an important element called nitrogen which is essential for maize growth and it also reduces crop diseases. Maize which have been intercropped with legumes grow very healthy." • "If the farm is less fertile, it becomes fertile when you grow legumes on it. So when you grow maize on it, the yield becomes much better."
Contradict	14	6	5	• "I have never used compost, my farm is good." • "No, [if you intercrop maize with legumes], maize will lack space and grow slowly."
Confusion	29	18	9	• "I don't understand the question, about planting materials." • "First of all, I still haven't understood what Nitrogen is." • "Why in our group do I not see others asking questions?" • "This old woman cannot send messages, please call her."
Inaccurate	7	2	0	• "A technique I used to increase fertility in my farm is to intercrop maize with pumpkins."
ReFarmer	341	21	3	• Farmer 1: "Do you know kikwila?" • Farmer 2: "I don't know, what is it?" • Farmer 1: "Kikwila is a legume variety which is planted near by the river, normally it creeps on trees, they are like lablab, they are odourless."
ReSua	655	357	217	
Total Messages	952	378	220	
Without ok/yes	803	171	79	

Table 3: Results: attrition and adoption

	Intent-to-treat		Treatment-on-the-treated		Control
	Treated	n	Treated	n	Mean
	(1)	(2)	(3)	(4)	(5)
Panel A: Attrition					
Planted maize	-0.003	369[a]	0.001	369[a]	0.804
	(0.049)		(0.079)		[0.030]
	{0.899}		{0.897}		
	[1.00]		[1.00]		
Attrition	0.008	468[a]	-		0.331
	(0.053)		-		[0.474]
	{0.874}		-		
	[1.00]		-		
Panel B: Adoption Outcomes					
Legume Practices:					
Intercropping 1	0.177***	257[b]	0.210***	257[b]	0.213
	(0.064)		(0.078)		[0.410]
	{0.009}		{0.007}		
	[0.037]		[0.028]		
Intercropping 2	0.113***	257[b]	0.134***	257[b]	0.150
	(0.041)		(0.049)		[0.357]
	{0.009}		{0.007}		
	[0.037]		[0.028]		
Other Legume Practices	-0.005	257[b]	-0.006	257[b]	0.118
	(0.038)		(0.048)		[0.323]
	{0.899}		{0.897}		
	[1.00]		[1.00]		
Legumes on Farm	-0.047	257[b]	-0.056	257[b]	0.335
	(0.044)		(0.051)		[0.473]
	{0.291}		{0.277}		
	[0.572]		[0.530]		
Organic Materials Practices:					
Organic Materials	0.017	257[b]	-0.020	257[b]	0.390
	(0.081)		(0.095)		[0.489]
	{0.835}		{0.831}		
	[1.00]		[1.00]		
Made Organic Fertilizer	0.147**	257[b]	0.174**	257[b]	0.126
	(0.073)		(0.084)		[0.332]
	{0.050}		{0.038}		
	[0.111]		[0.083]		
Organic Fertilizer MMP	0.044	257[b]	0.053	257[b]	0.154
	(0.059)		(0.010)		[0.361]
	{0.452}		{0.439}		
	[0.825]		[0.783]		

NOTES: This table shows the intent-to-treat and treatment-on-the-treated for adoption outcomes and attrition by regressing first difference of the outcome variable listed in the first column on treatment. Standard errors are robust and clustered at the village level and are shown in parentheses. P-values are shown in curly brackets and q-values in square brackets to correct for multiple hypothesis testing (Anderson 2008). The square brackets in column 5 represent standard deviations. All regressions control for use of other legume practices at baseline (1 = yes) and baseline knowledge score. [a]468 respondents were surveyed at baseline; 369 respondents were surveyed in both 2020 and 2021. [b]This sample size corresponds to the 257 respondents who grew maize in both years.

Table 4: Spillover Effects

VARIABLES	Control households in treated villages	Treated households	N
Legume Practices:			
Intercropping 1	0.179**	0.305***	257
	(0.0832)	(0.0807)	
	{0.037}	{0.000}	
	[0.208]	[0.001]	
Intercropping 2	0.124*	0.198***	257
	(0.086)	(0.071)	
	{0.158}	{0.008}	
	[0.316]	[0.017]	
Other Legume Practices	0.062	0.033	257
	(0.0469)	(0.042)	
	{0.192}	{0.437}	
	[0.316]	[0.538]	
Legumes on Farm	0.038	-0.019	257
	(0.082)	(0.068)	
	{0.646}	{0.784}	
	[0.507]	[0.812]	
Organic Materials Practices:			
Organic Materials	0.061	0.063	257
	(0.145)	(0.129)	
	{0.677}	{0.632}	
	[0.507]	[0.729]	
Made Organic Fertilizer	0.192**	0.271***	257
	(0.095)	(0.098)	
	{0.049}	{0.008}	
	[0.208]	[0.017]	
Organic Fertilizer MMP	0.115	0.130	257
	(0.123)	(0.114)	
	{0.358}	{0.264}	
	[0.507]	[0.359]	

NOTES: This table shows the spillover effects by regressing the outcome variables of interest on treatment groups, where group 0, control households in control villages, are the base group. All regressions use first differences and include the following controls: total land owned (acres), whether the household owns their main maize plot (MMP) (1 = yes), use of other legume practices at baseline (1 = yes), and baseline knowledge score. Standard errors are clustered at the village level and are robust. $***p < 0.01$, $**p < 0.05$, $*p < 0.1$. P-values are shown in curly brackets and q-values in square brackets to correct for multiple hypothesis testing (Anderson 2008).

Online Appendix

Appendix A: Extension Course Content

Table A1: Extension Course 1 Content

Date of sending	Round 1 Extension Content	Discussion Prompts
Jan 28	• 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: February 1-28; April 1-31; July 1-31. • 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 31		• *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 your soil that have or haven't worked for you.*
Feb 1	• 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 4	• 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 5	• 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 8		• 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?

Table A1: Extension Course 1 Content (Continued)

Date of sending	Round 1 Extension Content	Discussion Prompts
Feb 9	• 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 10		• 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 11	• 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 12	• 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, and keeps your soil healthy year after year.	• 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 15		• What techniques have you tried to improve your soil fertility? • What techniques would you like to try this year? Next year?

NOTES: Messages in italics were sent only to chat-group participants. All other messages and prompts were sent to all participants - treatment and control groups.

Table A2: Extension Course 2 Content

Date of sending	Round 2 Extension Content	Discussion Prompts
May 14		• *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 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!*
May 17	• Hello, this month you will receive messages from SUA about how to plant green manure and make compost for your farm. Thank you! • 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.	• Have you tried growing a green manure crop this year or in the past? Which one did you grow? • Do you know anyone who planted green manure?
May 18	• 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.	
May 19	• 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.	
May 20	• 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?

Table A2: Extension Course 2 Content (Continued)

Date of sending	Round 2 Extension Content	Discussion Prompts
May 27	• 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?
May 31	• 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?
June 3	• 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. • Compost has been proven to be the best type of organic fertilizer in drought-prone areas.	• Can you use compost to keep your soil moist during a drought?
June 4	• 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?
June 7		• Do you have time to make compost on your farm? Is making compost a valuable use of labor?
June 9	• 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?
June 11	• 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.	
June 15	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 the temperature drops in the pile, turn the pile up	
June 16	• 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?

NOTES: Messages in italics were sent only to chat-group participants. All other messages and prompts were sent to all participants - treatment and control groups.

Table A3: Extension Course 3 Content

Date of sending	Round 3 Extension Content	Discussion Prompts
Aug 2	• 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 3	• If you intercropped a legume with your maize crop, it should be ready to harvest before the maize. • 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.	• Did you plant a legume on your maize plot this year? If so, which variety did you plant? • Can you leave the legume crop residue on your field, or do you have other uses for this material?
Aug 4	• 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 5	• 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 6	• 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 9	• 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 10	• 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 11	• 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?

Table A3: Extension Course 3 Content (Continued)

Date of sending	Round 3 Extension Content	Discussion Prompts
Aug 12	• 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 16	• 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 17	• 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. • Alternatively, you can clear narrow rows across your field and plant the new crop in these rows.	
Aug 18	• 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 19	• 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 20	• 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. • It will also bring nitrogen from the air into the soil where it can be used by the maize crop.	• 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 21	• 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!*

NOTES: Messages in italics were sent only to chat-group participants. All other messages and prompts were sent to all participants - treatment and control groups.

Appendix B: Attrition

Table A4: Attrition

Variables	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)

NOTES: This table shows the results of an OLS regression of the baseline levels of all listed socio-economic and outcome variables on attrition. Robust standard errors are clustered at the village level and shown in parentheses. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

Appendix C: Full Sample

Table A5: Baseline balance and summary statistics

Panel A: Baseline balance	Control (SMS only)			Treated (SMS + Group chat)			
	n	mean	std. dev.	n	mean	std. dev.	difference
Socioeconomic variables							
Age of Respondent:	179	48.75	13.24	190	49.34	13.47	0.588
Gender of Respondent:	179	0.32	0.47	190	0.32	0.47	-0.003
Education of Respondent (years)	179	6.53	1.75	190	6.38	1.94	-0.152
Dependency Ratio	179	158.23	111.75	190	156.26	120.51	-1.971
Food Insecurity	179	2.23	1.86	190	2.15	1.80	-0.077
Land owned, acres	179	6.61	8.45	190	6.19	7.46	-0.425
Owned Main Maize Plot	150	0.90	0.30	160	0.91	0.29	0.006
Asset Index	179	0.07	2.12	190	-0.04	2.32	-0.114
Outcome variables: Adoption of practices							
Intercropping 1	150	0.18	0.39	160	0.14	0.35	-0.036
Intercropping 2	150	0.12	0.33	160	0.09	0.29	-0.026
Other Legume Practices	150	0.12	0.33	160	0.20	0.40	0.080**
Legumes on Farm	179	0.30	0.46	190	0.36	0.48	0.062
Produced Organic Materials	150	0.59	0.49	160	0.68	0.47	0.082
Made Organic Fertilizer	150	0.16	0.37	160	0.12	0.33	-0.035
Applied Organic Fertilizer	150	0.26	0.44	160	0.26	0.44	0.003
Panel B: Summary statistics	2020			2021			
	n	mean	std. dev.	n	mean	std. dev.	difference
Outcome variables:							
Intercrop w legume on MMP (1)	310^b	0.16	0.37	297^b	0.29	0.45	0.135***
Intercrop w legume on MMP (2)	310^b	0.11	0.31	297^b	0.20	0.40	0.091***
Other legume practices	310^b	0.16	0.37	297^b	0.11	0.31	-0.052
Legumes on farm	369^a	0.33	0.47	369^a	0.32	0.47	-0.007
Produced organic materials	310^b	0.64	0.48	297^b	0.22	0.41	-0.417***
Made organic fertilizer on-farm	310^b	0.14	0.02	297^b	0.13	0.02	0.012
Applied organic fertilizer MMP	310^b	0.26	0.44	297^b	0.05	0.23	−0.208***

NOTES: Panel A shows the balance of baseline socio-economic and outcome variables among all respondents who were reached at both baseline and endline, by regressing each baseline variable on the treatment indicator. The difference column shows the coefficient for this regression. Standard errors are robust and clustered at the village level. Panel B hows the results of t-tests comparing the mean of each outcome variable for the entire sample (treatment and control groups) between baseline (2020) and endline (2021). [a] The sample size of n = 369 corresponds to respondents who were reached at both baseline and endline. Of the 369 respondents, 310 cultivated maize in 2020 and 297 cultivated maize in 2021. [b]These questions were only asked to respondents who cultivated maize in the relevant year. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Appendix D: Spillover

Table A6: Balance, control in treatment villages versus control in control villages

	Control Households in Control Villages			**Control Households in Treated Villages**			
	N	Mean	Std. Dev.	N	Mean	Std. Dev.	Difference
Baseline variables							
Socioeconomic variables							
Age of respondent	46	47.41	13.55	81	47.06	12.06	-0.351
Gender of Respondent	46	0.28	0.46	81	0.33	0.47	0.051
Education of Respondent (years):	46	6.74	1.25	81	6.75	1.36	0.014
Dependency Ratio	46	151.21	97.35	81	155.37	125.19	4.154
Food Insecurity	46	2.11	1.81	81	2.14	1.84	0.031
Land owned (acres)	46	5.03	4.22	81	9.10	11.33	4.072**
Owned Main Maize Plot	46	0.83	0.38	81	0.94	0.24	0.112*
Asset Index	46	0.03	2.10	81	0.35	2.30	0.317
Outcome variables							
Intercropping 1	46	0.22	0.42	81	0.17	0.38	-0.045
Intercropping 2	46	0.15	0.36	81	0.11	0.32	-0.041
Other Legume Practices	46	0.11	0.31	81	0.14	0.34	0.027
Legumes on Farm	46	0.22	0.42	81	0.38	0.49	0.165
Produced Organic Materials	46	0.57	0.50	81	0.63	0.49	0.064
Made Organic Fertilizer	46	0.24	0.43	81	0.12	0.33	-0.116
Applied Organic Fertilizer	46	0.33	0.47	81	0.23	0.43	-0.092
Knowledge Score	46	2.54	2.36	81	2.88	2.51	0.333
Behavioral variables: Perceived self-efficacy (See Appendix F)							
General PSE score (mean)	46	3.35	0.78	81	3.41	0.77	0.068
PSE: Soil Fertility	46	4.09	1.13	81	3.69	1.32	-0.396**
PSE: Profits	46	3.80	1.13	81	3.72	1.33	-0.088
PSE: Food Security	46	4.17	1.16	81	3.95	1.37	-0.223
PSE: Furrowed Ridges	42	2.67	1.22	78	2.58	1.18	-0.090
PSE: Seed Spacing	24	3.96	0.20	34	3.82	0.58	-0.135
PSE: Intercropping	41	3.83	0.59	58	3.64	0.87	-0.191
PSE: Poultry Manure	46	2.85	1.26	80	2.95	1.25	0.102

NOTES: This table shows the balance of baseline socio-economic and outcome variables among control respondents in control villages versus control respondents in treatment villages, by regressing each variable on the treatment indicator for control households only. The treatment indicator here is equal to 1 for control households in treated villages, and equal to 0 for control households in pure control villages. All treated households are omitted. The Difference column shows the coefficient for this regression. Only households who grew maize in both years are included. Robust standard errors are clustered at the village level. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

Appendix E: Heterogeneity

Table A7: Heterogeneity Results

Variables	(1) Male	(2) Bottom Asset Quintile	(3) Poor Soil Quality
Treated	0.244**	0.189**	0.201**
	(0.116)	(0.0836)	(0.0961)
Male	0.0652		
	(0.104)		
Treated*Male	-0.141		
	(0.148)		
Bottom quintile		0.0178	
		(0.111)	
Treated*Bottom quintile		-0.0753	
		(0.122)	
Poor soil			0.0134
			(0.101)
Treated*Poor soil			-0.136
			(0.115)
Constant	-0.0001	0.0370	0.0392
	(0.0823)	(0.0706)	(0.0853)
Observations	257	257	257
R-squared	0.021	0.019	0.024

NOTES: This table shows the differential treatment impacts by gender, asset quintile and soil quality by interacting a dummy variable of these variables with treatment. The dummy variables capturing gender, asset quintile, and soil quality take the value of 1 if the respondent is male, the household is in the two lowest asset quintiles, and has poor soil quality (measured by CEC) on their main maize plot, respectively. Standard errors in parentheses are robust and clustered at the village level. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

Appendix F: Perceived Self-Efficacy

We elicit three measures of PSE. First, we elicit a general PSE score following Chen et al. (2001)'s New General Self-Efficacy (NGSE) scale which we loosely adapt to the domain of agriculture. NGSE consists of eight items that measure an individual's confidence in her ability to meet task demands and achieve goals (variable PSE Score). Next, we elicit two sets of domain-specific PSE measures following Schwarzer and Renner (2009) and Bandura (2006) who argue that PSE is linked to specific contexts and spheres of action. We include a series of task- and outcome-specific PSE measures. The outcome-specific measures ask farmers about their belief in their ability to bring about successful changes through their own actions, such as increase their family's food security, farming profits, and soil fertility (variables *Food Security*, *Profits*, and *Soil Fertility*, respectively). The task-specific measures ask farmers how confident they are in their ability to successfully implement certain tasks corresponding to the adoption outcomes we measure such as legume intercropping (*Intercropping*), making organic fertilizer (*Manure*), spacing seeds (*Seed Spacing*), and making furrows (*Furrows*). Below we provide more details on the ways we elicited PSE, adapting them to our context, including the specific questions asked.

None of the measures was a significant predictor of any adoption outcomes, and only one - *Intercropping* - registered a treatment effect, significant at the 10% level. Table A9 below presents the results of treatment effect on PSE measures (Table A8 shows the summary statistics and balance). Counterintuitively, participation in the chat groups reduced perceived self-efficacy over the intercropping task (statistically significant at the 10 % level), implying that the experience left users believing the task was more difficult than they had initially presumed, but nonetheless more likely to adopt. However, these results are no longer statistically significant when correcting for multiple hypotheses. Furthermore, we note that we may not have been able to detect an effect on PSE given our relatively small sample size.[7]

Finally, evaluating behavioral outcomes objectively is challenging, 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. Further research would benefit from collaboration with cognitive scientists and psychologists to improve on measures for capturing self-efficacy beliefs.

[7] For example, with a general PSE score of 3.387 (standard deviation of 0.774) at baseline, we would be able to detect a change of 0.272 given a sample size of 256 (the general PSE score ranges from 1 to 5). We use the *power twomeans 3.387, sd(0.774) n(256) power (0.8)* command in Stata to detect this change.

Survey Modules for PSE Elicitation

1. Generalized PSE: 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, General PSE Score, is calculated by taking the average over all items.

   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

2. Domain-specific PSE (includes all outcomes under Task-Specific PSE and Outcome Specific PSE): 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 in the tables below (Furrows, Seed Spacing, Intercropping, Manure, Soil-Fertility, Profits, Food Security).

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 (FAO, 2015).
>
> 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.
>
> 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:
>
> i. 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
>
> ii. 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

Table A8: Baseline balance and summary statistics, PSE

Panel A: Baseline balance	Control (SMS only)			Treated (SMS + Group chat)			
	n	mean	std. dev.	n	mean	std. dev.	difference
General PSE score (mean)	127	3.39	0.77	130	3.39	0.79	-0.003
PSE: Soil Fertility	127	3.83	1.26	130	3.93	1.18	0.096
PSE: Profits	127	3.75	1.25	130	3.88	1.15	0.137
PSE: Food Security	127	4.03	1.30	130	4.16	1.15	0.130
PSE: Furrowed Ridges	120	2.61	1.19	127	2.75	1.21	0.140
PSE: Seed Spacing	58	3.88	0.46	51	3.80	0.49	-0.075
PSE: Intercropping	99	3.72	0.77	110	3.79	0.59	0.074
PSE: Poultry Manure	126	2.91	1.25	130	3.05	1.14	0.141
Knowledge Score	127	2.76	2.46	130	3.37	2.38	0.613**

Panel B: Summary statistics	2020			2021			
	n	mean	std. dev.	n	mean	std. dev.	difference
General PSE score	257	3.39	0.77	257	3.76	0.82	0.372***
PSE: Soil Fertility	257	3.88	1.22	257	4.16	0.95	0.280***
PSE: Profits	257	3.82	1.20	257	4.06	1.06	0.245***
PSE: Food Security	257	4.10	1.22	257	4.28	1.00	0.182*
PSE: Furrowed Ridges	247	2.69	1.20	249	2.65	1.23	0.026
PSE: Seed Spacing	109	3.84	0.47	112	3.71	0.67	−0.139*
PSE: Intercropping	209	3.76	0.68	178	3.46	0.99	−0.2301***
PSE: Poultry Manure	256	2.98	1.19	249	2.89	1.15	−0.097
Knowledge score	257	3.07	2.43	257	4.98	2.57	1.918***

NOTES: Panel A shows the balance of baseline socio-economic and outcome variables among the 257 respondents who grew maize in both survey years, by regressing each baseline variable on the treatment indicator. The difference column shows the coefficient for this regression. Standard errors are robust and clustered at the village level. Panel B shows the results of t-tests comparing the mean of each outcome variable for the entire sample (treatment and control groups) between baseline (2020) and endline (2021). ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

Table A9: Measures of Perceived self-efficacy

	Intent-to-treat Treated	n	Treatment-on-the-treated Treated	n	Control Mean
	(1)	(2)	(3)	(4)	(5)
Knowledge Score	-0.523	257[a]	-0.063	257[a]	3.858
	(0.405)		(0.473)		[2.791]
	{0.897}		{0.894}		
	[1.00]		[1.00]		
PSE Score	0.018	257[a]	0.021	257[a]	3.573
	(0.125)		(0.146)		[0.813]
	{0.89}		{0.887}		
	[1.00]		[1.00]		
Task-Specific PSE:					
Furrows	-0.189	240[b]	-0.225	240[b]	2.663
	(0.235)		(0.273)		[1.178]
	{0.425}		{0.407}		
	[1.00]		[1.00]		
Seed Spacing	0.260	42[b]	0.346	42[b]	3.842
	(0.173)		(0.213)		[0.472]
	{0.154}		{0.104}		
	[1.00]		[0.713]		
Intercropping	-0.352*	151[b]	-0.396*	151[b]	3.668
	(0.172)		(0.204)		[0.793]
	{0.065}		{0.0523}		
	[1.00]		[0.713]		
Manure	-0.160	248[c]	-0.189	248[b]	2.912
	(0.185)		(0.295)		[1.171]
	{0.534}		{0.522}		
	[1.00]		[1.00]		
Outcome-Specific PSE:					
Soil Fertility	-0.051	257[a]	-0.061	257[a]	4.024
	(0.157)		(0.196)		[1.131]
	{0.764}		{0.757}		
	[1.00]		[1.00]		
Profits	-0.101	257[a]	-0.120	257[a]	3.929
	(0.188)		(0.219)		[1.174]
	{0.594}		{0.583}		
	[1.00]		[1.00]		
Food Security	-0.058	257[a]	-0.069	257[a]	4.173
	(0.226)		(0.262)		[1.160]
	{0.798}		{0.792}		
	[1.00]		[1.00]		

NOTES: This table shows the intent-to-treat and treatment-on-the-treated for PSE outcomes by regressing first differences of the outcome variable listed in the first column on treatment. Standard errors are robust and clustered at the village level (shown in parentheses). P-values are shown in curly brackets and q-values in square brackets to correct for multiple hypothesis testing (Anderson 2008). The square brackets in column 5 represent standard deviations. All regressions control for use of other legume practices at baseline (1 = yes) and baseline knowledge score. [a]This sample corresponds to the 257 respondents who grew maize in both years. [b]We only asked task-specific PSE questions to respondents who had not previously tried the given practice.