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Research

Technology adoption and weed emergence dynamics: social ecological modeling for maize-legume systems across Africa

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ABSTRACT. Ecological practices such as intercropping maize (*Zea mays*) with cowpea (*Vigna unguiculata* L.) have been promoted to combat parasitic weeds like *Striga* (*Striga asiatica*). Intercropping has been promoted across Africa as a Striga control practice (SCP) and food security measure. Despite past efforts, millions of smallholder farmers (cultivating < 2 ha of maize) still struggle to implement SCPs. Social and ecological factors that prevent SCP implementation are well documented in the literature, but their underlying interactions have remained elusive. System dynamics modeling can uncover these interactions and assess their effect on intercropping rates as well as Striga emergence. This study presents a participatory mixed methods approach to build a system dynamics model based on two theories: diffusion of innovations and resource pool dynamics. The model estimates the population of fields where Striga emerged in response to intercropped fields when various interventions were implemented. According to model simulations, if new policies are not enacted to support intercropping, Striga is likely to spread to 2,625,000 maize fields, parasitizing almost 75% of smallholder farms across Central Malawi by 2036. The participatory approach allowed us to evaluate several policies, one of which sustained enough adopters to limit Striga emergence to < 500,000 fields, reducing the weed's threat to food security. This policy considers how input costs and erratic rainfall can lead to disadoption, therefore, supporting the implementation of five to six consecutive years of intercropping by providing both fertilizer subsidies and demonstration plots. In this study, our participatory approach has shown to develop a model that can highlight interactions in social ecological systems, their leverage points, and how they can be exploited to develop effective food security policies.

Key Words: *intercropping, Malawi, mixed methods, Striga*, system dynamics

INTRODUCTION

Social ecological systems comprise humans and their interaction with the natural environment. These systems have been studied extensively, particularly among smallholder farmers cultivating less than two hectares across sub-Saharan Africa (SSA). In some instances, a cropping system or a farming practice is considered as an adopted technology. In one instance, adoption rates are affected by social factors, such as the interaction between adopters and non-adopters in a political and economic setting. In another, ecological factors affect sustained adoption overtime, such as climate variability, limiting the efficacy of farming practices. The interaction between these two factors represents system behavior (Van Strien et. al. 2019), which in many respects has remained elusive to practitioners disseminating ecological practices to improve farmer livelihoods and food security.

Despite countless attempts to disseminate ecological farming practices (e.g., intercropping), the cultivation of maize (*Zea mays*) as a monoculture has continued to be the dominant cropping system across SSA. Its cultivation has shown to lower soil fertility (Kureh et al. 2006), limit soil-phosphorous (P) availability (Abdul et al. 2012), and ultimately, perpetuate the spread of the parasitic weed Striga (*Striga asiatica*). As a parasite, Striga attaches to the root system of maize, sapping nutrients and causing yield losses, sometimes up to 100% (Pfunye et al. 2021). Although many farmers are aware of the relationship between monocultures and the spread of Striga, longstanding social and ecological factors have encouraged them to continue cultivating monocultures. For example, farmers tend to believe that a Striga Control Practice (SCP) like intercropping will provide lower maize yields than a monoculture; thus, this social factor prevails over the ecological benefits it can provide in the long term.

Intercropping maize with legumes, particularly cowpea (*Vigna unguiculata* L.), has shown to be an effective SCP across multiple settings in SSA (Khan et al. 2008). Various factors, however, can discourage the cultivation of maize-cowpea intercropping systems, including negative word of mouth (between farmers) or general disappointment with the practice (Masvaya et al. 2017). Multiple research methods have been used to study these factors (Silberg et al. 2017, 2020); however, they are difficult to combine within a single social-ecological framework (Meadows 2008). Methods, such as system dynamics modeling, can be used to understand why adoption rates vary overtime with respect to environmental factors (Oyo and Kalema 2016). More importantly though, system dynamics models can serve as management tools, indicating participatory strategies to manage environmental issues (Schlüter et al. 2019). With these tools, policy makers may avoid implementing traditional interventions that only focus on a single factor to resolve wider complex issues, but rather, develop interventions that work across scales to sustain ecologically balanced systems with responsible agricultural practices (Siman and Niewiarowksi 2023).

Our objective with this paper is two-fold. The first is to offer a novel framework to build models that reflect social-ecological systems. The framework fills a critical gap in the modeling and

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policy literature, whereby smallholder farmer perspectives are excluded from developing tools to evaluate system resiliency and policy options (Paas et al. 2021). The second objective is to develop a model for evaluating policies, specifically their effect on the adoption rates of ecological farming practices (in this case, intercropping) and their effect on the spread of pests across a country, like Malawi. Developing policies that foster system resilience via participatory approaches are critical (Epstein et al. 2021) given increasing climate variability and the call to support country-wide strategies for tackling food insecurity across SSA. We attempt to respond to this call for discovering policies to sustain adoption of ecological practices and tailoring them to withstand extreme events.

BACKGROUND

The state of Striga in Malawi

Prior to 2000, cereals were commonly intercropped with legumes across Malawi and the continent (Vandermeer 1992). Today, far less fields are intercropped. Some suggest agricultural policies in the past 20 years have discouraged these practices, incentivizing farmers to cultivate maize for export (Snapp and Fisher 2015). As a result, in the past two decades, Striga has emerged more frequently in smallholder fields across Malawi (Atera et al. 2013). The recent emergence of Striga may be attributed to reduced land per capita and augmented losses of soil fertility (via successive maize cultivation), which are drivers of parasitic weed emergence (Shackleton et al. 2009). Striga seeds are microscopic and can transfer to neighboring fields via wind, water, roaming livestock, farming tools, and maize seed (Wan and Wang 2019). The spread of Striga seeds is common across developing countries that rely on agriculture as a livelihood (Munthali et al. 2019, Fatch et al. 2020). The spread of Striga is amplified by its fecundity, as conservative estimates posit that one Striga plant can produce between 36,308 and 45,729 seeds (Abdul et al. 2012).

Multiple Malawian ministries have not specifically composed strategies to address the spread of Striga, but four policy frameworks have promoted practices (including intercropping) to address yield losses associated with the weed (Nyagumbo et al. 2016). These include the National Agricultural Policy (NAP) launched in 2016, the Adaptive Research Strategy (ARS) launched in 2015, the Malawi Growth and Development Strategy (MGDS) launched in 2012, and the Agriculture Sector Wide Approach (ASWAp) launched in 2010 (Stadler et al. 2017). The NAP, for instance, intended to increase legume and oilseed production via export markets along with the support of agricultural extension and value chain development. In another case, the ASWAp aimed to increase crop diversification by extending a Farm Input Subsidy Program (FISP) to synthetic fertilizer and legumes. Essentially, these two policies promoted the use of intercropping as a strategy to increase household food security and soil fertility.

Various programs and projects have been funded (not exclusively) under these four policy frameworks to increase agricultural diversity, profitability, and productivity. For example, the Soil Fertility Research Network for Smallholder Maize-Based Cropping Systems (Soil-Fert Net) promoted intercropping as a "Best Bet" soil fertility management practice (Mekuria et al. 2004). Soil-Fert Net also distributed small grants to fund events where collective learning could take place between farmers. With this network, scientists conducted experiments in smallholder fields, evaluating intercropping schemes while promoting them as SCPs. In other instances, farmer groups were created to hold demonstrations of how to properly cook legumes (Mhango et al. 2013). Other organizations created Early Childhood Development centers, acknowledging gender affected adoption (Mponela et al. 2021), and provided women access to demonstration plots to learn how intercropping systems could improve household nutrition (Gelli et al. 2018). Programs, such as Africa RISING (Research In Sustainable Intensification for the Next Generation), combined multiple aspects (e.g., best bet technology, farmer cooperatives) to increase seed access, extension, and visibility of demonstration plots (Timler et al. 2014)

Cultivation of cowpea as an intercrop

Cultivating maize-cowpea intercropping systems is a relatively new technology (to conserve soil and control Striga) in Malawi, as recent studies have found farmers are still learning about its benefits (Ngwira et al. 2020). However, planting cowpea with maize is not unheard of, as some extension planning areas have a long history of relay-intercropping the legume with maize. For example, in the Central and Southern regions of Malawi (Thyolo, Mulaje, and Chiradzulu) cowpeas are sown three weeks to two months after maize has been planted (Ngwira et al. 1990, Masvaya et al. 2017). In these extension planning areas, farmers plant the legume between rows several weeks after maize is planted, or once maize reaches physiological maturity, so cowpea does not compete for resources.

There are three primary barriers to cultivating maize-cowpea intercropping systems. In the first barrier, maize yield can decrease from 6% to 25% relative to sole maize cropping systems, depending on the spatial design (i.e., additive or replacement) of a field (Rusinamhodzi et al. 2012). These yield penalties can occur when maize and cowpea compete for nutrients (Lunduka et al. 2012, Snapp et al. 2018) and water in marginal environments (Silberg et al. 2020). In the second barrier, the price of legume seed is costly for a financially constrained smallholder farmer (Place et al. 2003). In addition, access to farming inputs and export markets are often limited to smallholder farmers, decreasing their chances of receiving a profit after adopting intercropping (Chinsinga and Poulton 2014). In the third barrier, when potential adopters lack an understanding of how intercropping controls weeds (e.g., allelopathy), they are less likely to adopt the practice (Silberg et al. 2019).

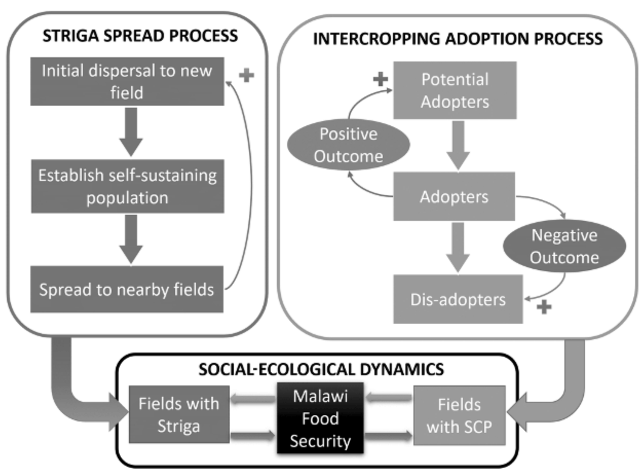
APPROACH AND METHODS

The conceptual framework of this paper was structured around an objective to understand the dynamics between agricultural policies and adoption rates of ecological practices. We draw from different methodological frameworks, which outline the critical variables to include in a social ecological model, the relationships between variables in the model, and their underlying feedback behavior. In the context of Malawi, we investigate the adoption of maize-cowpea intercropping practices as a Striga control measure among smallholder farmers (from this point forward in the text, any mention of SCP refers to the cultivation of a maize-cowpea intercropping system). We combine qualitative and quantitative methods to first construct the model and then incorporate data and apply inputs; second, validate the model to run policy scenarios; and third, discuss the most effective intervention for sustaining SCPs. This comprehensive framework lays a foundation in understanding the intricate interplay between adoption and Striga emergence rates, but specifically, contributes to the development of research-informed policies aiming to promote sustainable agricultural practices tackling food insecurity.

Methodological framework

A mixed methods approach often integrates two or more methods simultaneously or in a sequential manner (Maxcy 2003). Our first set of methods was informed by the theory of resource-pool dynamics (see "Striga Spread Process" in Fig. 1), which explains how the spread of an invasive species (via wind, rain, human, or livestock) increases exponentially across an agroecosystem, only slowing once most of the landscape is saturated (Leffler and Ryel 2012). Then, our second set of methods was informed by innovation diffusion theory (Rogers 2003). From this theory, we draw from the Bass model of technological diffusion (Bass et al. 2000), which explains how information is shared between farmers via word of mouth until reaching market saturation (see "Intercropping Adoption Process" in Fig. 1). In combining theories from both the social and natural sciences, we created a social-ecological framework to assess the interaction between SCP adoption and Striga spread, and ultimately, its effect on food security in Malawi (see "Social-Ecological Dynamics" in Fig. 1).

Fig. 1. Mixed social-ecological modeling framework. SCP = Striga control practice.



Systems modeling is one research method used to develop simplified representations of agroecosystems and the diffusion processes (Reinker and Gralla 2018). These models are dynamic, as they highlight direct (and indirect) relationships between humans and nature (Beall and Zeoli 2008). Each relationship can create reinforcing (or balancing) behavior, guiding the fluctuation of a specific stock or rendering it unchanged. For example, social connectivity (e.g., sharing of negative information) can override the utility a smallholder farmer could gain from adopting an agricultural practice, regardless of its profit (Knowler and Bradshaw 2007, Kopainsky et al. 2012). High connectedness in systems, particularly between social factors, can create resiliency, but also resistance to change (Downing et al. 2014). Previous studies have used systems modeling to estimate the influence of social factors on adoption rates of soil fertility management technologies like intercropping (Tambang 2010, Grabowski et al. 2019). In this study, we created a system model based on data gathered from focus group discussions, discrete choice experiments, mediated modeling, and crop modeling (see Table 1).

Study area

The study was conducted over a one-year period in 2017 across two Central districts of Malawi, Dedza and Ntcheu, which are located in the Kasungu Lilongwe Plain (14.1667°S, 34.3333°E) and Rift Valley Escarpment (14.7500°S, 34.7500°E), respectively. Within these districts, four extension-planning areas were selected for data collection, namely Linthipe, Kandeu, Nsipe, and Golomoti. These extension planning areas were specifically chosen based on the growing challenge of Striga reported by farmers in the past decade (Silberg et al. 2020).

Focus group discussions

Three focus group discussions were facilitated in July 2017 across three extension planning areas to determine what practices farmers were aware of to control Striga and the sources that informed them about these practices. Participants were purposefully selected from a roster of smallholder farmers affiliated with the Africa RISING program. The program conducted action-based research with smallholder farmers in the region beginning in 2013 and ended in 2019. Each focus group discussion consisted of 12–15 participants. Discussion groups included lead farmers, managing demonstration plots or experimenting with different SCPs as well as those not affiliated with Africa RISING. In each group, an equal number of male and female participants were present to ensure one gender did not dominate the discussion (Fern 1982). Facilitators were extension agents and ensured all member opinions were heard.

During focus group discussions, smallholders were asked about the attributes of SCPs (e.g., maize yield return, intensity of labor) that influenced their decision to adopt them (refer to Appendix 1 for more description on questions asked). After, they were asked about the individuals and organizations that informed them about the SCP. A narrative analysis was conducted by uploading transcripts into MAXQDA® (VERBI GmbH 2019). The analysis informed the design of the following data instrument- a discrete choice experiment.

Discrete choice experiments

Following focus group discussions, we conducted discrete choice experiments. The method examines trade-offs that farmers are willing to make for one practice over another based on its attributes (Ortega et al. 2016, Waldman et al. 2017). In this study, the trade-off we determined was the quantity of maize (kg/ha) farmers were willing to sacrifice to lower Striga via intercropping (Silberg et al. 2020). In the experiment, 10 smallholder farmers together were presented six hypothetical scenarios (often referred to as choice tasks), one scenario at a time. In each scenario, smallholder farmers chose one of three options (i.e., two different SCPs or opt out). They indicated their choice privately by pointing to a card behind their back so as not to influence one another's choices (refer to Appendix 9 for more description about the steps of the discrete choice experiment). Each option was presented as physical props representing five attributes with one of three levels (Silberg et al. 2023). The attributes included soil fertility benefit, Striga spread, labor requirement, legume yield, and maize yield.

Table 1. Mixed methods employed in study.

System nature	Step	Method	Social-ecological systems component
Social	1a	Focus group discussions	- Sources of information that lead to adoption
	1b	Questionnaire/literature review	- Length of time until seeing positive or negative result/s from intercropping - Length of time until adopting/disadopting intercropping across an entire farmer field - Source/s informing information about intercropping
	2a	Discrete choice experiments	- Maize yield willing to sacrifice for lower *Striga* emergence - Maize yield loss that would lead to disadoption of intercropping
	3a	Focus group discussions/mediated modeling	- Institutions that encourage or discourage intercropping adoption
Ecological	2b	Household questionnaire	- Percent population that received positive/negative result from intercropping
	3b	Climate database operated by Malawian Meteorological Services	- Monthly rainfall in the Central Region - Monthly temperature in the Central Region
	4	Results of crop model/literature review	- Striga emergence in a farmer field response to specific intercropping - Maize yield response to Striga emergence and climate (in a smallholder farmer field)

A stratified sample of 215 smallholder farmers (n = 215) was taken from a roster (N = 298) to select participants from the Africa RISING program across four extension planning areas (Linthipe, Golomoti, Nsipe, Kandeu). From August to September 2017, 125 participants were selected to participate in the discrete choice experiment who were affiliated with farming households that expressed Striga as a primary challenge to maize production. The remaining 90 smallholder farmers were selected alphabetically by the last name of the household head until the total for each extension planning area amounted to 50–60 participants.

After the discrete choice experiments, the participants answered a questionnaire to reveal the sources that informed about the SCP (refer to Appendix 2 and 3 for more description about the sources). Then, to estimate the time it took to adopt intercropping, participants stated a range (in years) it would take them to cultivate an intercropping system across their entire field after learning about the SCP. These sources included word of mouth, observation, or other communication channels (Silberg et al. 2020). Then, the questionnaire asked if they adopted the SCP (based on that source), what outcomes occurred from adopting the SCP (e.g., increased maize yield), and finally, who they shared the results with.

Mediated modeling

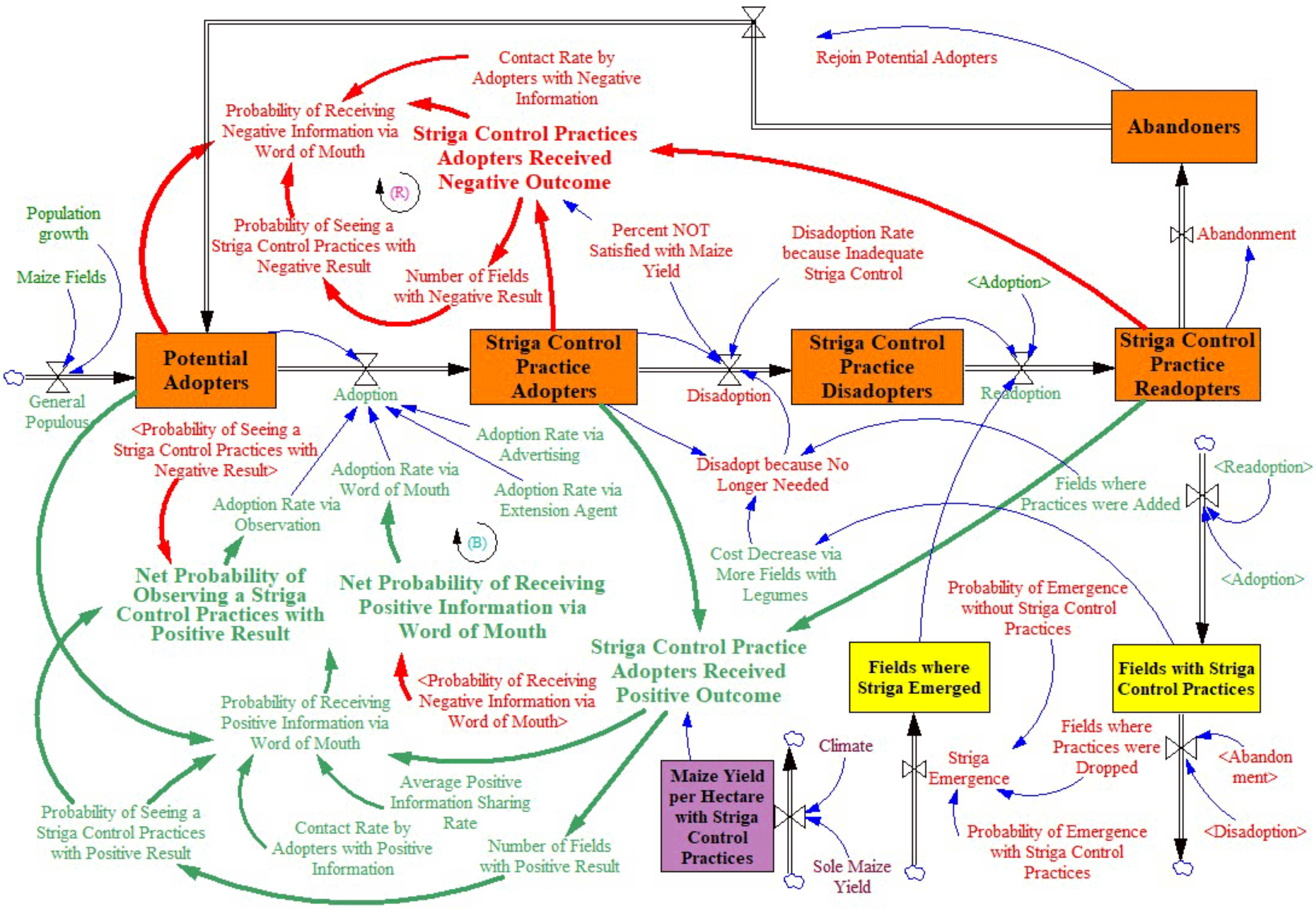
Mediated modeling has been used to understand social ecosystems (Beall and Zeoli 2008) and the processes behind their longstanding issues such as failed adoption of sustainable practices (Pahl-Wostl and Hare 2004). In September 2017, we facilitated a mediated modeling workshop to exchange perspectives between three stakeholder groups (n = 12) about Striga to catalyze social learning (Van den Belt 2004, Schmitt Olabisi et al. 2016). Participants were purposefully selected and separated into three gender-balanced groups including (1) lead farmers from Africa RISING and agricultural extension development officers; (2) private sector employees (e.g., fertilizer salesperson); (3) local agricultural researchers and district level agricultural policy makers. Participants were first asked to define Striga emergence in a smallholder farmer field as a problem and the primary drivers of its spread across a wider social-ecological system. Then, they were asked to convert these problem statements into causal loop diagrams (Inam et al. 2015). In this sense, statements are broken down into several interrelated causes, one feeding into another. A detailed photo of the causal loop diagrams can be found in Appendix 7.

Causal loop diagrams are the basis of stock and flow models, represented as arrows connected to blocks, feeding/decreasing populations (Andersen et al. 2007). Participants converted diagrams into three models with the assistance of systems modeling researchers (illustrations of these models are in Appendix 8). Facilitators ensured all members contributed to the models by drawing three boxes within one another to represent scales. The inner most box represented a field, the next an extension area, and the outer most being the Central Region of Malawi. Variables were added to each scale and linked. As the workshop closed, each group's model was connected to form a single model of stocks and flows. The lead investigator inquired where to get inputs to apply to the stocks/flows so as to run the model at a later date. Participants indicated inputs for social variables could be sourced from the discrete choice experiment and questionnaire data, but variables related to nature required data outside of the study (e.g., meteorological data).

Crop modeling

A crop model was developed (Silberg et al. 2021) from October to December 2017 using variables cited in the scientific literature. The crop model evaluated the extent intercropping controlled Striga emergence across a smallholder field. Model variables were applied with inputs found in local studies that investigated germination, flowering, seed dynamics, as well as other phases of the Striga lifecycle. The model allowed us to analyze Striga emergence in a one-hectare maize-based field managed by a smallholder farmer, and then, extrapolate the results of the weed spreading across multiple fields. Different smallholder practices affected specific stages of the Striga lifecycle (see Fig. 1 in Silberg et al. 2021). Smallholder knowledge about their effects on each phase varied (see section 4.1 in Silberg et al. 2020). One result from the model that was necessary to operationalize our wider social-ecological model was the length of time it took to eradicate Striga from a field by cultivating an intercropping system and/or applying fertilizer.

Fig. 2. Striga emergence and intercropping adoption model.



Developing a model to represent a social ecological system

Stock and flow model

The data collected from the four previous methods informed the variables to include and build a stock and flow model, named the Striga Emergence and Intercropping Adoption Model (SEIAM). The SEIAM was built using Vensim® (see Fig. 2) and its purpose was to serve as a decision support tool for evaluating hypothetical interventions intended to control the spread of Striga (across 20 years). The boxes in the SEIAM represent stocks, which act as outputs. These stocks are integral equations, simulating how a population fluctuates according to interacting flows (Forrester 2007). Flows are represented in Figure 2 by arrows pointing in and out toward the stock. Variables are connected to the flows (i.e., arrows), mediating how fast populations feed into or leave a stock (Kopainsky et al. 2012). The green arrows represent a positive event that would support the adoption of intercropping, while the red arrows represent a negative event that would deter adoption. The blue arrows represent a neutral event. If more than one arrow is connected to a variable, this indicates the variable is calculated by two or more combined inputs. A more detailed version of the model is presented in Appendix 6.

In the SEIAM, farming households from the general population can choose to adopt a SCP, making them "Striga Control Practice Adopters." Then, they can remain with the SCP, discontinue (making them "Striga Control Practice Disadopters"), take up the SCP again (making them "Striga Control Practice Readopters"), or abandon the SCP (making them "Abandoners"). The adoption or disadoption of a SCP is driven by numerous variables, most notably maize yield (see variables connected to "SCP Adopters Received Post Outcome"). The percent of households that receive positive or negative outcomes is based on whether the maize yield they receive exceeds what they are willing or unwilling to sacrifice for intercropping. Maize yield is a function of SCP adoption, climatic conditions (rainfall and temperature), and fertilizer application (Ngwira et al. 2013, 2014).

Different variables in the SEIAM influence the percent of positive and negative outcomes (colored in green and red, respectively) households receive from having a SCP in their field. Adoption is driven by the four variables that begin with "Adoption rate via," including word-of-mouth, observation, extension agent (Kabambe et al. 2013), and advertising (e.g., pamphlet, radio). As more fields with SCPs are seen, if optimal maize yields are

Table 2. Source of model inputs.

Variables connected to topic	Source
Yield thresholds that led to adoption or disadoption of Striga control practice	1. Random parameter logistic regression in willingness to pay space (Discrete Choice Experiments) 2. #35–41 (Household Questionnaire)
Contact rate between farmers based on positive or negative results received from adopting a Striga control practice	1. #27/31B, 27C/31C, 27D,31D (Household Questionnaire)
Percent that receive a negative or positive outcome from adopting a Striga control practice	1. #27/31B (Household Questionnaire)
Adopt a Striga control practice based on word of mouth, agricultural extension, observation of other farmer fields	1. #25B/29A, 25A/29A, 26A/20A (Household Questionnaire)
Rate of negative or positive outcome observed	1. #25B/29A, 26a/30A, 25B/29B (Household Questionnaire)
Relationship between field parasitized with Striga and knowledge about Striga	1. #8–14 (Household Questionnaire)
Striga attachment rate to maize in response to different Striga control practices	1. Scenario runs (Cropping Systems Model) 2. Literature (Rusinamhodzi et al. 2012)
Maize yield percent loss/gain based on rainfall and attachment	1. Maize module (from Cropping Systems Model) 2. Literature (Denning et al. 2009, Jayanthi et al. 2013)
Number of fields with/without Striga	1. #14–15, 20 (Household Questionnaire[†])
Percent adopters continued/discontinued Striga control practice after receiving positive/negative results	1. #26D/30C, 26F/30E, 26G/30F (Household Questionnaire)
Time required prior to hearing, seeing, or receiving information about Striga control practice	1. #34B, 34C, 34D (Household Questionnaire)
Climate variables (e.g., rainfall, daily temperature) across a 20-year time span (1996–2016)	1. Monthly rainfall and temperature data (Malawian Meteorological Service Data Bank)

[†] The household questionnaire is attached in Appendix 2.

met, more potential adopters can see these positive results and be encouraged to adopt. Growth of adopters increases the population of fields with SCPs, decreasing the cost of inputs as more legume seed become available locally. Oppositely, if more fields have Striga, weed emergence will also increase due to the spread of seed from neighboring fields. These paradigms are examples of feedback behavior. Feedback behavior is indicated in the SEIAM with pink and turquoise circular arrows with "R" and "B" located in the middle, respectively. Feedback loops are largely responsible for system behavior (Forrester 2007).

Variable specifications

All orange stocks are considered as farming households cultivating two fields each. Their initial populations were set according to summary statistics calculated from household questionnaire data. These statistics were then extrapolated across the Central Region. For example, the questionnaire found that 65.0% of households intercropped legumes in some form with their maize; therefore, the starting value for "Striga Control Practice Adopters" stock was calculated by multiplying 0.65 to 987,815 farming households. The same order of calculations was conducted to apply inputs for "Fields where Striga Emerged" and "Fields With Striga Control Practices" (i.e., yellow stocks). We acknowledge this percentage may exceed intercropping rates (44%) across the region (Katengeza et al. 2019), as the questionnaire was conducted in extension planning areas where various maize-legume intercropping systems have widely been promoted for +5 years (Waldman et al. 2017).

Rainfall data (from 1996 to 2016) was critical to calibrate the model. Competition for water between cowpea and maize (in an intercropping system) can increase during periods of drought (Rusinamhodzi et al. 2012), resulting in yield losses (e.g., 8–50%) and discouraging adoption (Silberg et al. 2019). Average rainfall in the past 40 years during the growing season (from November to April) was 1421 mm. If rainfall fell below 1065 mm, maize yield losses began to occur in the SEIAM. More specifically, if there were 12 consecutive days where rainfall did not reach 3 mm per day, fields with SCPs experienced higher yield losses (22.3%) than sole-maize (Arndt et al. 2016). Rainfall data used in the SEIAM indicated years 7–15 had favorable rainfall while the other years did not. Fertilizer application buffered maize yields (6.0%) in fields with SCPs (versus those without) against drought (Rusinamhodzi et al. 2012). Table 2 summarizes the sources used for each input. Equations and values for each input are stated in Appendix 4 and 5.

Model initiation

The SEIAM simulates Striga emergence with respect to SCP adoption across maize-based fields, beginning in 2016 and ending in 2036. These fields are confined to the Central Region, where 55,720km² are arable (Leete et al. 2013) and 38% percent (21,173.6 km²) is currently allocated to agriculture (SNDP 1998). We estimate that there are 1,192,139 households in the Central Region (NSO 2016, World Bank 2017), 85% which rely on agriculture as a primary livelihood. On average each household rents or owns between 1.96 and 2.00 ha of land, allocating 0.87 ha to maize cultivation (Katungi et al. 2017).

Typically, smallholder households cultivate two maize fields; a low and high fertility field where they apply or allocate less and more inputs to, respectively (Mhango et al. 2013). These fields range in size, but recent household questionnaires suggest they are 0.365 ± 0.052 ha/field (Li et al. 2021). Based on the following information, the SEIAM assumes one household consisting of 5–6 members (World Bank 2017) cultivates two maize fields that are 0.417 ha each, amounting to 823,838 ha (1,975,630 fields) of maize already being cultivated in the Central Region, leaving 528,658 ha (or 1,267,764 fields) to be cultivated with an intercropping system. Field population with SCPs, therefore, cannot exceed 1,352,496 ha (3,243,395 fields).

Table 3. Variables selected for sensitivity analysis.

Type of variable	Variable name	Business as usual (BAU) & supporting calculation	Lower/upper bound	Value comparison
Social	Adoption Rate via Agricultural Extension Agent (indirectly connected to Adoption)	69.0% (106 households indicated they received information about intercropping from an outside agent)	34.1%/95.0%	The lower bound and BAU value surpasses rates (36.5% and 51.0%) indicated in studies investigating extension services across the Central Region (Steinfield et al. 2015)
	Average Positive Information Sharing Rate (indirectly connected to Adoption and Disadoption)	7% (households indicated they shared positive information with 10/153 individuals whereas negative information was shared with 2/153)	3.5%/10.5%	Few studies quantified the number of individuals (e.g., 10) farming households share positive information with about a technology (Kopainsky et al. 2012), let alone positive versus negative aspects (Grabowski et al. 2019). Fear of Striga seed spreading from a neighboring field may be why more positive news was shared (Nyang'au et al. 2018)
Ecological	Probability of Emergence with Striga Control Practice (indirectly connected to Striga Emergence Increase)	65.0%	97.5% and 32.5%	Modifications rates falls in range with emergence rates in sole maize fields without SCPs when compared to those with SCPs as outlined in Schulz et al. (2003)
	Probability of Emergence with Striga Control Practice (indirectly connected to Striga Emergence Decreases)	65.0%	97.5% and 32.5%	Modifications of these rates concur with control rates outlined by Midega et al. (2014) when emergent rates were monitored in sole maize fields relative to fields with maize-cowpea intercropping systems

Model test and runs

There are different tests that can validate a model. We used the extreme-conditions test to assess and discover any flaws in our model structure (Barlas 1989). Afterward we conducted a sensitivity test to specify hypothetical policies to run scenarios in the SEIAM.

Validation and sensitivity

To conduct an extreme test, maximum/minimum values are inputted across several auxiliary variables to see if the result in the model (i.e., the output) demonstrates an S-curve. If the model demonstrates an unlikely output, then its structure, connections, and/or input values may not be an accurate reflection of a social-ecological system (Senge and Forrester 1980). For example, if the stock "Fields with Striga Control Practices" exceeds the "Total Maize Fields" (3,243,395 fields), it would be an inaccurate reflection of the system. We conducted several extreme conditions tests, modifying "Field Size," "Probability of Eradication with a Striga Control Practice," and "Climate" (specifically rainfall). After changing the inputs of these variables to their maximum or minimum values, output graphs illustrated an "S" curve. This showed an exponential increase in "Total Maize Fields," before slowing to a plateau, thus, validating model output.

After validation, we conducted a sensitivity analysis. A sensitivity analysis is employed to determine resistance and/or resilience to model output against changes in inputs (Aivazidou and Tsolakis 2021). In social-ecological models, an empirical sensitivity analysis is recommended when variables do not have fixed inputs. One by one, we modified the inputs of three variables: "Adoption Rate," "Disadoption Rate," "Striga Emergence Increases," and "Striga Emergence Decreases." Inputs were adjusted by +/- 50% from their original values. We chose these variables because of their direct influence to the stocks "Fields where Striga Emerged" and "Fields WITH Striga Control Practices." Then, we evaluated stock outputs against their business as usual (BAU) output. Input values were based on literature or by calculating an upper/lower bound for a confidence interval (see below in Table 3).

Scenarios run in model

We determined which hypothetical scenarios to run based on noticeable changes in stock outputs when modifying inputs. We conducted a scenario analysis to determine whether increased fertilizer subsidies, agricultural extension, demonstration plots, or a combination of the three showed noticeable changes in the model. We were focused on changes in "Fields with Striga Control Practices" and "Fields where Striga Emerged." In a sequential manner, we ran one scenario, assessing its output, and then added others, keeping the previous scenario in place. Scenarios were run for 20 consecutive years (1996–2016). Each scenario is explained in Table 4 and based on past policies mentioned in the subsection "The state of Striga in Malawi."

RESULTS

Summary statistics

Questionnaire data highlighted how different information sources affected the adoption, disadoption, readoption, and abandonment of SCPs (see Table 5). Socioeconomic characteristics were heterogeneous across participants (Silberg et al. 2020). Data applied to the SEIAM variables not only pertained to the adoption of maize-cowpea intercropping, but also the adoption of similar SCPs. This was done to gain a greater sample size for the study. The SCPs included manure, ash, maize bran, and fertilizer application, which are also referred to as soil fertility management practices.

The difference between the percentages for "Received information" and "Implemented SCP after" was smaller for agricultural extension (via agent) when compared to observation. This finding indicates that extension is a more effective strategy for increasing the adoption of intercropping. Households seemed to place higher trust in agricultural extension than field observation. More trust in extension when compared to observation is not

Table 4. Model scenarios.

Item	Baseline scenario (business as usual)	Scenario 1 (demonstration plots)	Scenario 2 (demonstration plots and agricultural extensionists)	Scenario 3 (demonstration plots and fertilizer subsidy)	Scenario 4 (agricultural extensionists and fertilizer subsidy)
Policy strategy	None	Increased demonstration plots	Increased demonstration plots and visits from agricultural extension development officers	Increased demonstration plots and initiated fertilizer subsidy	Increased probability of receiving agricultural extension and initiated fertilizer subsidy
Variable/s modified in model	None	Number of fields with positive result	Number of fields with positive result; probability of receiving agricultural extension	Number of fields with positive result; probability of emergence with Striga control practices	Probability of emergence with Striga control practices; probability of receiving agricultural
Input/s changed in variable/s	None	Current value of number of fields with positive result plus 100,000 to 300,000 across 20 years (15,000 added per year)	Current value of number of fields with positive result plus 100,000 to 300,000 across 20 years (15,000 added per year); from 0.69 to 0.95 (for probability of receiving agricultural extension)	Current value of number of fields with positive result plus 100,000 to 300,000 across 20 years (15,000 added per year); †from 0.4 to 0.2 (for probability of emergence with Striga control practices)	‡From 0.4 to 0.2 (for probability of emergence with Striga control practices); from 0.69 to 0.95 (for probability of receiving agricultural extension)

† Demonstration plots are assumed to take the form of a 10m x 10m experimental plot, which is sown as part or in addition to a potential-adopter's field. The values specified in the scenario are based on the population of adopters in the model as well as studies that indicate experimental plot populations (e.g., 3000 in a town) that encourage adoption (Kerr et al. 2007).
‡ The scenario rests under the assumption that adopter receive fertilizer incentives for cultivating legumes as was done in the past with the Farm Input Subsidy Program.

Table 5. Rates of receiving information about Striga control practice and implementing after.

Information source	Received information (n = 158)	Received information and implemented Striga control practice after (n = 158)
Word of mouth	153/158 (96.8%)	143/158 (90.5%)
Agricultural extension	109/158 (69.0%)	97/158 (61.4%)
Observation	75/158 (47.5%)	59/158 (37.3%)
Advertisement	16/158 (10.1%)	9/158 (05.7%)
Aggregate average	88/158 (55.85%)	77/158 (48.73%)

consistent with the literature (Stone 2007); however, the finding indicates that adoption associated with observation can appreciate (and depreciate) quickly, which is consistent with literature (Kopainsky et al. 2012). The highest drop in trust occurred with advertisement (43.6%), resulting in a less effective strategy to disseminate information about intercropping. This may be due to the education level of smallholders or because no one is there to explain the intricacies of the practice. Maize yield resulted in the highest percentage of positive and negative outcomes reported by smallholders after adopting SCPs; thus, maize yield was the leading reason for disadoption (see Table 6). Of the 82.3% of participants who received a positive outcome from adopting a SCP, only 20.0% reported outcomes not related to maize yield gains. Of the 17.5% that received a negative outcome from adopting a SCP, only 5.0% reported outcomes not related to maize yield loss.

Table 6. Outcomes received by maize-cowpea intercropping.

Positive outcome from Striga control practice	Maize-cowpea intercropping system as a single Striga control practice (n = 41)	All Striga control practices (n = 158)
Lower Striga emergence	26 (63.4%)	135 (94.4%)
Higher maize yield	23 (56.1%)	98 (75.3%)
Higher soil fertility†	20 (48.8%)	92 (70.8%)
Lower overall weed biomass	0 (00.0%)	14 (10.8%)
Increased water retention	0 (00.0%)	13 (10.0%)
Aggregate positive outcome	35 (85.4%)	130 (82.3%)
Negative outcome from Striga control practice	**Maize-cowpea intercropping system as a single Striga control practice (n = 41)**	**All Striga control practices (n = 158)**
Higher Striga emergence	1 (2.4%)	20 (71.4%)
Lower maize yield	1 (2.4%)	15 (53.6%)
Aggregate negative outcome	9 (22.0%)	28 (17.7%)

† Increased soil fertility also included reduced erosion/improved soil structure/texture. Increased maize yield also included aggregate food increase.

Farmers shared positive and negative information with peers differently via word of mouth. Positive outcomes (46.0%) were mentioned more frequently about all SCPs than negative outcomes (20.0%). Smallholders may have shared positive outcomes more frequently than negative outcomes with neighbors out of fear of seed landing on their farm from adjacent fields, thus, encouraging their neighbors to prevent Striga emergence via intercropping. Farmers tend to share negative outcomes about SCPs more than positive outcomes (Friedlander et al. 2013), although in this study, negative outcomes may have been shared less given the apprehension of losing agricultural extension (e.g., Africa RISING).

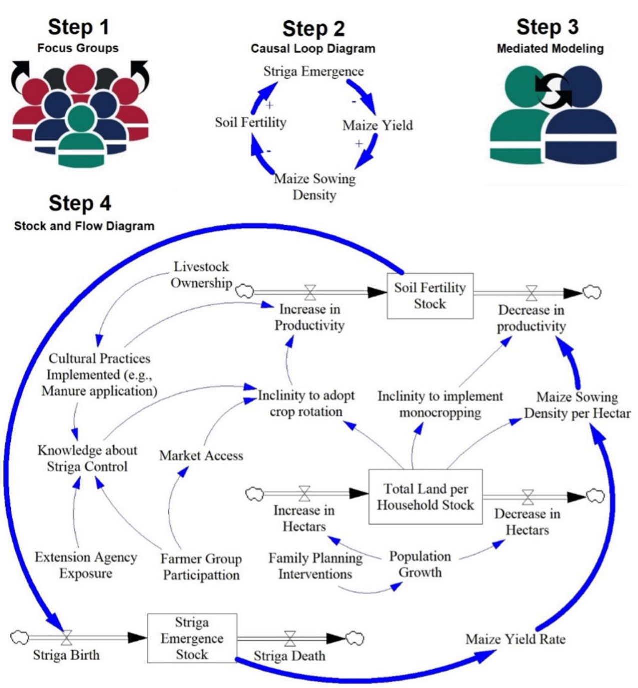
Mediated modeling results

Three causal loop diagrams and three stock and flow models were created at the mediated modeling workshop. These steps are outlined in Figure 3. The model created in Step 4 of Figure 3 was used as the base to build the more comprehensive SEIAM. The remaining diagrams and models are attached in Appendix 6. During Step 1 at the workshop, participants discussed how emergence decreased maize yield, which obligated farmers to increase sowing density to compensate for crop loss. As a result, soil fertility decreased because of continuous maize cultivation without replenishing land with nutrients, favoring Striga emergence. This cycle is presented in Step 2. In Step 3, participants created three smaller models; the first illustrating how Striga emergence was attributed to growing household size (e.g., more family members to feed); thus, shrinking landholdings and increasing land degradation. The second model shows how population growth among adopters decreased seed costs because smallholders could exchange more seed amongst themselves. The third model presents how observation of intercropping fields both drove and discouraged adoption, leaving farmers to discuss the maize yield gains or losses as a result from adopting SCPs. The three models were connected in Step 4, which were later expanded upon to create the SEIM, adding other variables to develop a full representation of the social-ecological system.

Model scenarios

We ran several policy scenarios in the SEIAM to determine how to increase SCP adoption over a 20-year period and whether a population of adopters could be reached to eradicate the invasive weed.

Fig. 3. Causal loop diagram and stock and flow model created by participants.

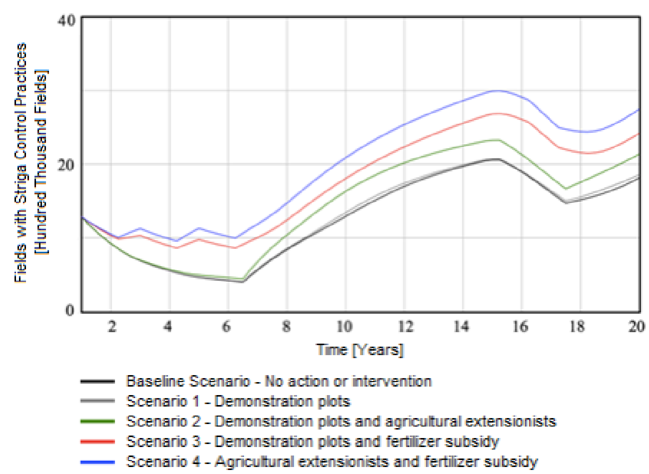


Social variables in the SEIAM

The Baseline Scenario demonstrated realistic results, as the population of intercropping fields rose and fell according to positive and negative trends of word of mouth/climate, respectively. For example, in Figure 4, sharp drops in intercropping fields occurred during Years 1, 3, 5, 15, and 16, which were years when abandonment was high because of unfavorable climatic conditions. According to current programs and growing conditions, intercropped fields will increase by 300,000 fields, representing only 9.25% of the 3.24 million fields available for intercropping in the Central Region. Negative word of mouth/observation strongly discouraged potential adopters to intercrop in later years, despite seeing 8 consecutive years of positive outcomes (i.e., Year 7 to 15). These overriding social factors indicate that without an intervening program, the long-term opinion and implementation of intercropping is jeopardized.

Scenario 1 illustrates that more demonstration plots in the Central Region will likely have little effect on the intercropping population, illustrating < 5.0% difference between the scenario and the Baseline. With the addition of agricultural extension (Scenario 2), there were several thousand additional fields when compared to the Baseline Scenario on any given year with favorable climatic conditions. More noticeable changes occurred

Fig. 4. Fields with Striga control practices according to policy scenarios,

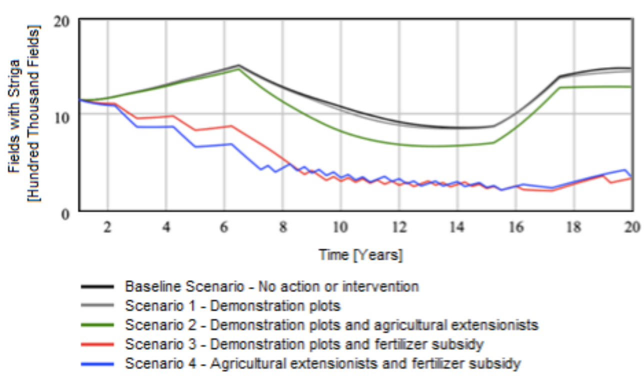


when demonstration plots were combined with fertilizer subsidies (Scenario 3), as fertilizer compounded the positive effects SCPs had during years with favorable climatic conditions. This resulted in approximately 600,000 more fields with SCPs than the result in the Baseline Scenario in Year 20. If demonstration plots were replaced by agricultural extension (Scenario 4), this resulted in approximately 500,000 to one million more fields with SCPs in any given year. The reason for the large difference between scenarios with fertilizer subsidies and scenarios without, was that fertilizer increased the adoption rate of SCPs by as much as 29.0% in years with favorable climatic conditions and 17.0% in years without favorable climatic conditions. This effect buffered adoption against negative word of mouth. The result agrees with adoption rates observed in past programs involving fertilizer such as FISP (Koppmair e al. 2017). Extension (without fertilizer subsidies), on the other hand, had little effect on negative word of mouth during years with unfavorable climatic conditions, increasing the adoption rate of SCPs by only 6.0% (when compared to the Baseline Scenario).

Ecological variables in the SEIAM

Under the Baseline Scenario, the population of fields with Striga will grow from 1.14 to 1.47 million across the 20-year period (see Figure 5). The result indicates both fields with Striga and fields with SCPs will grow at similar rates. The reason for this equal growth is that the population of fields with SCPs is more sensitive to disadoption than fields with Striga. For example, disadoption can occur when a farmer experiences just one year of drought; however, Striga emergence in a field slows after 3 consecutive years (at a minimum). Even at peak of adoption in Year 15, where the population of fields with SCPs reaches 2.1 million, 1.13 million fields are experiencing a decreasing trend of Striga emergence, but still spreading seed to neighboring fields.

Fig. 5. Fields where Striga emerged according to policy scenarios.



An intervention of solely demonstration plots (Scenario 1) only led to 6000 less fields with Striga when compared to the Baseline Scenario. With the addition of agricultural extension (Scenario 2), the difference between the Baseline Scenario was more pronounced, leading to 350,000 less fields with Striga. More noticeable changes occurred when demonstration plots were combined with fertilizer subsidies (Scenario 3), as synthetic inputs augmented the control effect cowpeas had over Striga, resulting in approximately 1.1 million less fields with Striga when compared to the Baseline Scenario in Year 20. If demonstration plots are replaced with agricultural extension (Scenario 4), the difference would be roughly the same as Scenario 3. Fertilizer inputs, decreased the time a field took to eradicate Striga while increasing maize yield, compounding the positive outcomes adopters received and spoke about to potential adopters. Scenarios 3 and 4 suggest that to decrease premature disadoption, safety nets, like fertilizer subsidies, should be provided to food-insecure households that generally drop a SCP after experiencing one year of negative outcomes (Holden and Mangisoni 2013).

Summary of scenarios

The results of the SEIAM illustrated that even under favorable climatic conditions, which would support intercropping, the spread of Striga emergence will be sustained across a 20-year period. Each Policy Scenario addressed the spread of Striga across the Central Region differently (see Table 7). Although Scenarios 1 and 2 increased the population of fields with SCPs, emergence still prevailed. Scenario 3 demonstrated a slight increase in population of fields with SCPs. Intercropping decreased the population of fields with Striga, but the population rebounded in later years. Scenario 4 echoed similar populations of fields with Striga across the 20-year time period, but increased the population of fields with SCPs to a threshold where Striga could not return. The finding argues that increased agricultural extension alone will not address the spread of Striga without providing some form of agricultural inputs to support intercropping.

Sensitivity

Variables indirectly connected to initial adoption were modified to find which one influenced the population of Fields with SCPs and Field with Striga most. Furthermore, we investigated which variables we could change marginally to have the most impact on the two stocks of interest. The social variable that caused the largest change in Fields with SCPs with the smallest change in its original value was "Probability of Receiving Agricultural Extension." The ecological variables that caused the largest change in Fields with Striga with the smallest change in their original values were "Probability of Emergence with Striga Control Practice" and "Probability of Emergence with Striga Control Practice." These social and ecological variables are illustrated in the more comprehensive model that can be found in Appendix 6.

Social variables of the SEIAM

Initial behavior observed in the SEIAM from our sensitivity analysis was that farmers shared both positive and negative aspects about intercropping, whereas agricultural extension development officers only shared positive aspects. Despite all the positive aspects agricultural extension agents share about intercropping, their effect on adoption could be cancelled out by one season of bad maize yields (see year 6 and 17 in Fig. 6 part "a"). Changes in the variable "Probability of Receiving Agricultural Extension" had little effect on "Fields with Striga" because of the persistent spread of Striga from neighboring fields. These fields came from the growing population of readopters that abandoned intercropping after receiving a second negative outcome (see part "b" in Fig. 6). Aggregately, these two outcomes in the SEIAM sustained a disadopter population cultivating enough fields without SCPs that could spread more Striga, no matter how large the population of the stock "Fields with Striga Control Practices" grew. The behavior of the SEIAM aligns with pest invasive theories, where a minimal population of weeds can override the influence of an intervention given their high fecundity (With 2002).

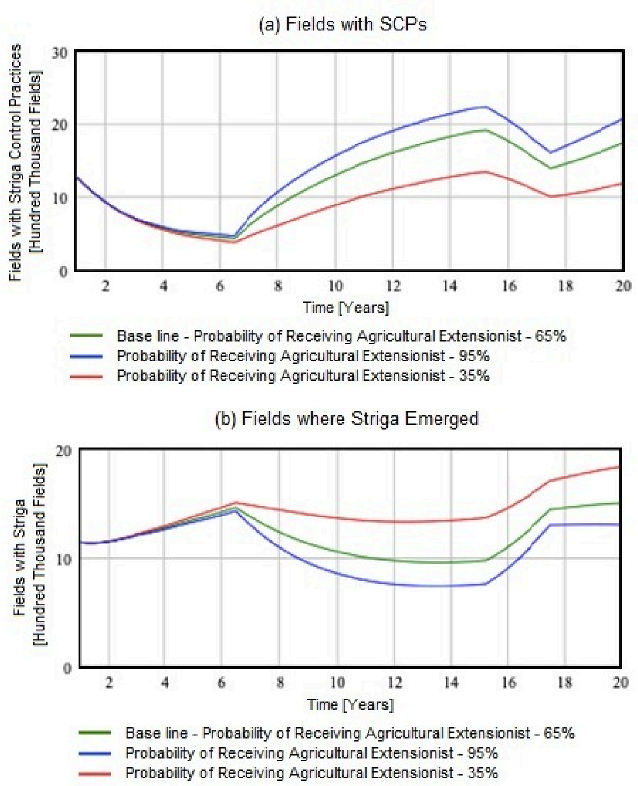
Ecological variables of the SEIAM

Augmented control of Striga emergence via intercropping decreased seed dispersion in the SEIAM (see part "a" in Fig. 7), but had little effect (if any) on adoption (see part "b" in Fig. 7). Little change in adoption was attributed to endogenous variables including "Adoption via Word of Mouth" and "Adoption via

Table 7. Summary of scenario results across 20 years.

	Baseline scenario (business as usual)	Scenario 1 (demonstration plots)	Scenario 2 (demonstration plots and agricultural extensionists)	Scenario 3 (demonstration plots and fertilizer subsidy)	Scenario 4 (agricultural extensionists and fertilizer subsidy)
Policy/strategy to control the spread of Striga	None	Increased demonstration plots	Increased demonstration plots and visits from agricultural extension development officers	Increased demonstration plots and initiated fertilizer subsidy	Increased probability of receiving agricultural extension and initiated fertilizer subsidy
Fields with SCPs in Year 20	1,600,000	1,620,000	2,400,000	2,000,000	2,600,000
Fields where Striga emerged in Year 20	1,470,000	1,464,000	1,120,000	370,000	370,000
Noticeable change/s in outputs	None	Increased probability of seeing a Striga control practice with positive result	Increased probability of seeing a Striga control practice with positive result; increased adoption	Increased maize yield per hectare with Striga control practice & probability of emergence with Striga control practices; increased probability of seeing a Striga control practice with positive result	Increased maize yield per hectare with Striga control practice & probability of emergence with Striga control practices; increased adoption

Fig. 6. Agricultural extension effect on farmer fields.



Observation." The inputs of both variables comprise the several benefits received by implementing a SCP. The benefit of receiving lower Striga emergence was marginal when compared to the other benefits in the SEIAM, such as receiving higher maize yield. Maize yield will increase with intercropping, but only under favorable conditions and once Striga has been eradicated from a field (which takes up to five years). In a five-year time period drought can occur, leading to disadoption.

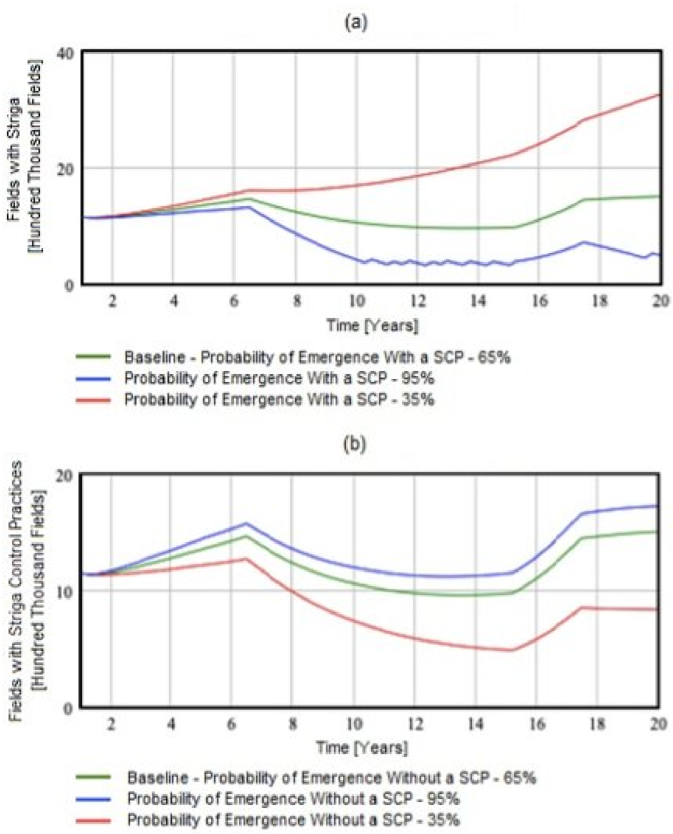
DISCUSSION

The SEIAM highlights several critical results for food security and weed management researchers and practitioners. Study insights regarding control and adoption rates can be applied to other weeds and control practices (respectively) elsewhere across Africa; however, model inputs would have to be modified. Under current dissemination and adoption rates in the Central Region of Malawi, Striga rates will persist over a 20-year period, even with six consecutive years of optimal climatic conditions that deliver sufficient maize yield with the SCP.

Without a sustained effort of limiting emergence to a threshold of < 500,000 fields, *S. asiatica* seeds will continue to spread across the Central Region of Malawi, input costs will persuade households to discontinue, and/or erratic rainfall will reduce yields enough where households will abandon the SCP. In terms of increasing adoption and managing Striga emergence, model results indicate that more economical interventions, such as fertilizer subsidies bundled with demonstration plots, are as effective as more costly interventions, such as fertilizer subsidies bundled with agricultural extension. This finding aligns with adoption studies stating that inorganic inputs are needed to sustain maize yields within intercropping systems during initial years of adoption (Denning et al. 2009, Jayanthi et al. 2013), but can be tapered off in later years.

The SEIAM differed from previous dynamic adoption models in five ways (see Grabowski et al. 2019, for example). First, the model was built by the very smallholder households it intended to simulate. Second, input values were calculated from adoption data collected from the same smallholder households. Third, it used choice model data to create yield thresholds to specify what households were (un)willing to accept from adopting SCPs. Fourth, maize yield response was verified with crop model data to estimate Striga spread with respect to SCP adoption. Fifth, the SEIAM estimated disadoption rates based on yield thresholds being met (or not), its subsequent effect on Striga spread as well as implications for food insecurity. These five processes were used to model the interactions between adoption rates and intercropping performance (as opposed to analyzing them separately), therefore better assessing the future efficacy of agricultural interventions (Marenya and Barrett 2007).

Fig. 7. Emergence effect on farmer fields.



Although the study provided valuable insights for addressing Striga while considering factors related to food security, it had limitations. First, the SEIAM may have been too sensitive to drought. Generally, after a cowpea-maize intercropping system is implemented across multiple seasons, it can buffer maize yield against drought (Nyagumbo et al. 2016, Boillat et al. 2019) because legumes can improve soil structure, which is associated with higher water retention (Lunduka et al. 2012) and fertilizer response (Snapp et al. 2018). Hence, future models should include two different stocks, one as short-term adopters (1–3 years) and the other as long-term adopters (> 3 years), where the latter does not abandon abruptly when a drought event occurs because intercropping can make cropping systems more resilient to climate change. Although the SEIAM was not spatially parametrized (e.g., weed seed transfer per ha) to perform like longstanding crop models (see Masere and Worth 2016), it highlights key social ecological interactions.

CONCLUSIONS

This study contributes a novel mixed-methods approach to understand the dynamic behavior of social-ecological systems in Malawi and across Africa. By employing this social-ecological systems framework, we highlight feedback behavior between social and ecological factors across 20 years (1996–2016), which may override future policy interventions (Van Strein et al. 2019) related to the spread of Striga. The feedback loop between maize yield and farmer satisfaction with intercropping outweighed any other benefit the SCP could deliver. Policy interventions, therefore, only focusing on Striga control as a benefit of intercropping are unlikely to sustain adoption rates if they do not support the practice via agricultural inputs (Schulz et al. 2003).

The feedback between a small population of disadopter fields and seed spread supersedes a high population of adopters in terms of emergence across the region. Policy interventions that aim to manage the spread of Striga across a country must be cognizant of the population of fields with Striga emerging relative to the fields that have no SCP. They should not focus on an adopter population alone. The time needed for a SCP to eradicate a weed with respect to the population of fields needed to remain weed-free should be considered before fully investing in an intervention. Given that implementation rates differ according to information source, “trust development” should be a topic of discussion as new extension efforts are developed. Additionally, given that implementation rates differed according to information source, “trust development” should be a topic of discussion as new extension efforts are developed.

We recommend researchers and practitioners to assess interventions with multiple stakeholders more frequently using models that represent their social-ecological systems (Paas et al. 2021). If these interventions are effective, they can be presented as scenarios to policy makers and funders (Schlüter et al. 2019). Scenarios not only illustrate projected outcomes based on future investment, but also underlying factors that sustain (or threaten) food security. System modelers should consider increased climate variability because this will likely increase the volatility of adoption rates. The intention of the SEIAM was not to estimate exact outcomes of variables, but demonstrate behavioral trends between variables across space and time. Additional discrete choice experiments may be needed to recalibrate the SEIAM as population grows. The maize yield smallholders will sacrifice to adopt intercropping is likely to decrease as land per capita shrinks (Mponela et al. 2021). New theories can be used to address issues related to scale such as item response theory (Borges et al. 2023).

The structure and values applied to the SEIAM were robust in the eyes of the stakeholders (i.e., the farmers). Maize yield and adoption trends are responsive to extreme climatic events, adding to model credibility. Predicted outcomes should not be treated as exact figures, as parameterization of the model was based on basic processes behind crop and weed physiology. The objective of the study was to provide a credible framework and proof of concept for developing dynamic models that capture social-ecological interactions. Despite several shortcomings, a favorable view of the structure and results of the SEIAM by local stakeholders may be the most important result given their proximity to Striga emergence and its interventions. They were the ones that created multiple causal loop diagrams, connected diagrams across social and ecological boundaries, and finally, responded to questionnaires to provide data for the purpose of running scenarios. Had several causal loops been incorrect, model scenarios would have likely illustrated false results. The results of the SEIAM adds legitimacy to the collaborative approach employed to construct social-ecological systems. This approach can better position food security practitioners to create interventions, evaluate them, and determine if they are as dynamic as the weeds they wish to control and the farmers they wish to assist.

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Data Availability:

The study involved human subjects and the authors certify that the work was done with prior approval for human subjects research by an institutional review board. Ethical approval for this research study was granted by Michigan State University and approval number x17-062e; i053237. The data/code that support the findings of this study are available on request from the corresponding author, T.R.S. None of the data/code are publicly available because of restrictions (i.e., they contain information that could compromise the privacy of research participants).

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Objective of discussion: Discover traits of Striga control methods that are of most concern to smallholder farmers

Introduction: Today we are going to ask you about your knowledge and practices regarding weed management. The intention of this interview is to first, gather information so researchers can better understand Striga management strategies conducted by farmers like yourself. Then according to your description of these weed management strategies, determine reasons for your implementation and/or preference.

1. Are you familiar with Striga? If yes, what do you know about Striga (e.g., lifecycle, identification, effect on yield, seed transport)?

2. Have you ever faced challenges with Striga? When do you first notice Striga in your field (specifically at what physiological stage/height)?

3. If you've had Striga, how many years?

4. If you've seen Striga in your field, did it affect your maize yields? How much?

5. Are you <u>aware</u> of any practices used to **<u>treat</u>** Striga (e.g., manual pulling)? If so, please describe (e.g., timing, required inputs, etc.).

6. Are you <u>aware</u> of any practices used to **<u>prevent</u>** Striga (e.g., soil fertility techniques)? If so, please describe (e.g., timing, required inputs, etc.).

7. How did you hear about these practices? How did you learn about them (e.g., experimentation, extension, NGO, etc.)?

8. Would you consider any of these practices traditional? That is, agricultural extension, an NGO or an outside party did not promote them to you. They were passed on from generation to generation. Please indicate which ones.

9. Among the **treatment** practices you mentioned, do you implement any of them? If so, please describe (e.g., timing, required inputs, etc.). Among those you don't implement, why not?

10. Among the **preventative** practices you mentioned, do you implement any of them? If so, please describe (e.g., timing, required inputs, etc.). Among those you don't implement, why not?

11. What are some of the control methods you used because inputs were subsidized (or given free) to you? What were the inputs? Describe why you did them because the inputs were offered? Why wouldn't you do them without the inputs?

12. How do the treatment and preventative practices control Striga (e.g., reduce emergence the next season, remove before seeds are mature, etc.)? Essentially, what are the mechanisms or processes behind them that control Striga?

13. What goals or objectives do you take into account before choosing/implementing a Striga control practice? (Give the example of choosing a legume seed. You would perhaps look at taste, yield, cooking time, etc.)

14. Rank these traits from most important to least according to importance. Then, rank the practices you mentioned from most to least effective in controlling Striga.

15. Rank the methods you mentioned from most to least preferred. While they may be effective, we are trying to determine which ones are the practiced among farmers.

Date:____
Beginning Time:____
Ending Time:____
Location:____

Cholinga: *Kumvesesa za kaufiti ndi njira zothesera kaufiti zomwe alimi ang'onoang'ono amagwiritsa ntchito*

Mawu oyambirira: Lero timafuna tikambilane zomwe mumadziwa ndi kuchita zokhuzana ndi kasamalilidwe ka zomera zosafunika mmunda. Cholinga cha kucheza kwathu ndikufuna kupeza uthenga ofunika kuti anthu a kafufuku ngati ineyo amvesese mmene kaufiti amasamalilidwa ndi alimi ngati inuyo. Kutengera ndi zomwe mutafotokoze, ndifunsaso zifukwa zomwe munasankhira njira zomwe mukugwiritsa ntchito posamala ndi kuthana ndi zomera zomera zokha mmunda.

1. *Mukudziwapo kalikonse kokhudzana ndi kaufiti? Ngati eya, mukudziwa chani zokhuzana ndi kaufiti? (monga mayendedwe a moyo, maonekedwe ake, mmene zimakhuzira zokolola).*

2. *Mwakumanako ndi mavuto ena liwonse ndi kaufiti? Munamuzindikila ali potani mmunda mwanu? (kakulidwe, katalikidwe)*

3. *Ngati mwakumanako ndi mavuti ndi kaufiti, zachitika kwa zaka zingati?*

4. *Ngati munakhalako ndi kaufiti mmunda mwanu, anakhuzako zokolola zani? Zinakhuzika bwanji?*

5. *Mukudziwapo ndondomeko/njira ina iliyonse yomwe mungathe kuthana ndi kaufiti (monga kuzula pamanja)? ngati ilipo ifotokozeni (monga nthawi yoyenera, zipangizo zofunika)?*

6. *Mukudziwapo ndondomeko/njira ina iliyonse yomwe mumatsata poteteza kaufiti (monga njira zobwezeretsa nthaka)? ngati ilipo ifotokozeni? (monga nthawi yoyenera, zipangizo zofunika)?*

7. *Munadziwa bwanji za ndondomeko zimenezi? Munaziphunzira bwanji? (monga kuyesela, alangizi, mabungwe ndi ena otero)*

8. *Pa ndondomeko/njira zimenezi, ndi ziti zomwe zili zamakolo? Kutanthauza kuti alangizi, mabungwe kapena anthu ena obwera sanazakuphunzitseni. Izi ndi njira zomwe zakhala zikutsatidwa ndi mibadwa yonse.*

9. *Pa ndondomeko/njira zothana ndi kaufiti zomwe mwatchulazi, mukugwiritsa ntchito ziti? Chonde fotokozani zomwe mukugwiritsa ntchito (monga nthawi yoyenera, zipangizo zofunika ndi zina zotero). Pa zomwe simukugwiritsa ntchito, ndi chifukwa chani simukuzigwiritsa ntchito?*

10. *Pa ndondomeko/njira zoteteza kaufiti zomwe mwatchulazi, mukugwiritsa ntchito ziti? Chonde fotokozani zomwe mukugwiritsa ntchito (monga nthawi yoyenera, zipangizo zofunika ndi zina zotero). Pa zomwe simukugwiritsa ntchito, ndi chifukwa chani simukuzigwiritsa ntchito?*

11. *Ndi ndondomeko ziti zothana ndi kaufiti zomwe munagwiritsa ntchito chifukwa zipangizo zinali zotsika mtengo mokuthanidzani kapena zinapatsidwa mwaulele? Zinali zipangizo zanji? Fotokozni chifukwa chimene munagwiritsa ntchito njirazi chifukwa zipangizo munapatsidwa mwa ulele? Ndi chifukwa chani simukanatsatila ndondomeko/njira zi popanda zipangizo zimenezi?*

12. *Ndondomekozi/ njirazi zinathana kapena zinateteza bwanji kaufiti? (monga kuchepesa kumera kwa kaufiti mu chaka china, kuthana nazo zisanayambe njere)*

13. *Ndi zinthu ziti zomwe mumaona musane sankhe ndondomeko/ njira yothana ndi kaufiti? (pelekani chitsanzo: mukamasankha mbewu ya mtundu wa nyemba mumaona kakomedwe kake, zokolola komanso nthawi yomwe zimatenga kuti zipsye)*

14. *Ikani zinthu zomwe mumaganizira musanasankhe ndondomeko/ njira yothana ndi kaufiti mu dongosolo kuyambira yofunika kwambiri kumalizira yosafunika. Mukatero, ikani ndondomeko/ njira zomwe munatchula zothana ndi kaufiti mu dongosolo kuyambila yomwe imagwira kwambiri kumalizila yosagwira bwino*

15. *Ikani ndondomeko/ njira zothana ndi kaufiti mu dongosolo kuyambira zomwe zimakondedwa pakati pa alimi kumalizira ndi zomwe sizikondwedwa. Njira zina zitha kukhala zogwira kwambiri koma tikufuna tidziwe zomwe alimi ambiri amakonda kugwiritsa ntchito*

Tsiku:

Nthawi yoyambila:

Nthawi yomalizira:

Malo:

Informed Consent

Enumerator (say to respondent): Today we will be asking you about your knowledge about Striga and its control practices. You can contact Timothy Silberg or the Institutional Review Board at Michigan State University and/or withdraw from the study without penalty at any time. *Wofunsa (nenani kwa wofunsidwa): Lero tikufunsani za mmene mumadziwira kaufiti komanso njira zotetezera kaufiti. Mutha Kulumikizana ndi a Timothy Silberg kapena Komiti imene imawayang'anira ku Michigan State University komanso muli ndi ufulu wosiya kuyankha mafunso ndipo palibe chilango chilichonse pochita izi.*

Section A. Basic member & household characteristics

1. District:____
2. EPA: ____
3. Respondent Name, Age, Gender & Education: __________________________________
4. Village: ____
5. Date: ____
6. Enumerator: ____
7. Household identification (HHID):____

Section B. Perceptions and awareness of Striga

8. Are you familiar with Striga? **Y** **N**
   Mumadziwa tchire la mmunda lotchedwa kaufiti?
9. Can you visibly tell the difference between annual weeds and Striga? **Y** **N**
   Mungathe kusiyanitsa pakati pa tchire lina (udzu wa mmunda) ndi kaufiti?
   a. If YES, how can you identify Striga among annual weeds?
   (List up to three) (**Code A)____**
   Ngati ndi choncho, mungamudziwe bwanji kaufiti pakati pa tchire la mtundu wina uliwonse?
10. Do you find there is a difference between the ways annual weeds affect your maize yield versus the way Striga affects your maize yield? **Y** **N**
    Mumatha kusiyanitsa mmene tchire lina lonse limavutitsira chimanga kuyerekeza ndi mmene kaufiti amachitira?
    a. If YES, how so? (List up to three) (**Code B)________________________________**
    Ngati ndi choncho, zimasiyana bwanji?
11. Can you visibly tell where Striga is in your field before it emerges? **Y** **N**
    Muli ndi kuthekera kodziwa kuti pamalo pali kaufiti ngakhale asanamere?
    a. If YES, how can you tell Striga is present before it emerges from the soil?

(List up to three) (**Code C)____**
Ngati ndi choncho, mumadziwa bwanji?

12. Are you aware how Striga attacks maize? **Y** **N**
Mumadziwa mmene kaufiti amaonongera chimanga chathu?
    a. If YES, please describe (List up to three) (**Code D)_______________________**
Ngati ndi choncho, fotokozerani
13. What does **the enumerator** consider their general knowledge of Striga is? (Circle one)
Wofunsa akuwona kuti woyankha akumudziwa bwanji kaufiti? (zungulizani chimodzi)
0 **1** **2** **3**
(Unaware) (Little Knowledge) (Some Knowledge) (Very Knowledgeable) *Sakumudziwa Akumudziwa pang'ono Akumudziwa ndithu Akumudziwa kwambiri*

Section C. Striga history & impact

14. Please indicate the number of fields you cultivated this past season where maize was the primary crop (#)____
Pa minda imene munalima ndi ingati imene chimanga chinatenga gawo lalikulu m'chaka chapitachi?
    a. How many fields had Striga? (#)______________________________________
Ndi minda ingati imene munamera kaufiti?

High Fertility Plot

15. Did this plot have striga?
Munganene kuti kaufiti ndi vuto lalikulu pa ulimi wanu? **Y** **N**
***Note- If farmer responds NO, please go to #20)**
****Ngati mlimi ayankha kuti ayi, pitani ku funso #20)***
    a. If **YES**, what year did these challenges begin?___________________________
Ngati ndi choncho, vutoli linayamba m'chaka chiti?
16. Comment on Striga emergence on the plot.
Mundiuzeko za kameredwe ka kaufiti mu minda imene ili ndi vutoli?
    a. Striga emergence was patchy **Y** **N**
Kaufiti anamera patalipatali
        i. Please comment on the soil conditions of this plot
        (List up to four) (**Code E**)_____________________________________

Nthaka ndiyotani mmindayi?

b. Striga emergence extended across the entire plot **Y** **N**

Kaufiti anamera m'munda wonse?

i. Please comment on the soil conditions of this plot

(List up to four) (**Code E**)____________________________________

Nthaka ndiyotani mmindayi?

17. Now think about this season.

Mwa minda mwatchulayi, ndi chaka chiti chimene mudayamba kuonamo kaufiti?

a. What month and week did you plant maize?__________________________

Tchulani mwezi komanso sabata imene munadzala chimanga?

b. Did the maize plant begin to wilt before you saw Striga?

Mbewu yanu ya chimanga inayamba kufota kaufiti asanamere? **Y** **N**

i. What month and week did the maize begin to wilt? *Ndi mwezi komanso sabata iti mmene chimanga chanu chinayamba kufota?*________________week #/month #)

ii. At what physiological stage did the maize begin to wilt?

(List 1) (**Code F**)____

Chimanga chinayamba kufota chitakula bwanji/motani?

18. Now think about once Striga emerged.

Taganizani mmene kaufiti anamera.

a. What week (#) and month (#) did you begin seeing Striga **emerge** from the soil?____

Unali mwezi uti komanso sabata iti mmene kaufiti anayamba kumela?

b. At what physiological stage was the maize when Striga emerged?

(List 1) (**Code F)**____

Chimanga chinali chitakula bwanji/motani mmene kaufiti amaonekera?

c. Please comment on the health of maize once Striga emerged

(List up to three) (**Code G)**____

Thanzi la chimanga linali bwanji mmene kaufiti amamera?

19. Was there a cob at harvest? **Y** **N**

Chimanga chinali chili ndi tiana mmene kaufiti amamera?

a. If YES, please comment on cob size at harvest

(List up to 3) (**Code G**)______________________________________

Ngati ndi choncho, Zisononkho zinali zazikulu bwanji pa nthawi yokolola?

b. **That season,** what yield did you receive compared to others that did not have Striga (List 1) (**Code H**)__________________________

Munakolola zochuluka bwanji poyerekezera ndi zaka mmbuyomu (mmene munalibe kaufiti)?

***Note – If farmer states that all fields had Striga, ask them how their yields compared to those of their neighbors**

****Ngati mlimi wanena kuti minda yonse inali ndi kaufiti, afunseni za zokolola zawo poyerekeza ndi minda yoyandikana nayo.***

c. In addition to Striga, did you face any other challenges on this plot related to productivity?
Panalinso mavuto ena omwe anakhudza ulimi wanu kupatulapo vuto la kaufiti? **Y** **N**

I. List up to 3 (**Code I**)__________________________

Low Fertility Plot

20. Did this plot have striga?
Munganene kuti kaufiti ndi vuto lalikulu pa ulimi wanu? **Y** **N**
***Note- If farmer responds NO, please go to #25)**
****Ngati mlimi ayankha kuti ayi, pitani ku funso #25)***
    a. If **YES**, what year did these challenges begin?__________________________
    Ngati ndi choncho, vutoli linayamba m'chaka chiti?
21. Comment on Striga emergence on the plot.
Mundiuzeko za kameredwe ka kaufiti mu minda imene ili ndi vutoli?
    a. Striga emergence was patchy **Y** **N**
    Kaufiti anamera patalipatali
        i. Please comment on the soil conditions of this plot
        (List up to four) (**Code E**)____________________________________
        Nthaka ndiyotani mmindayi?
    b. Striga emergence extended across the entire plot **Y** **N**
    Kaufiti anamera m'munda wonse?
        i. Please comment on the soil conditions of this plot
        (List up to four) (**Code E**)____________________________________
        Nthaka ndiyotani mmindayi?
22. Now think about this season.
Mwa minda mwatchulayi, ndi chaka chiti chimene mudayamba kuonamo kaufiti?
    a. What month and week did you plant maize?__________________________
    Tchulani mwezi komanso sabata imene munadzala chimanga?

b. Did the maize plant begin to wilt before you saw Striga?

Mbewu yanu ya chimanga inayamba kufota kaufiti asanamere? **Y** **N**

i. What month and week did the maize begin to wilt? *Ndi mwezi komanso sabata iti mmene chimanga chanu chinayamba kufota?*________________week #/month #)

ii. At what physiological stage did the maize begin to wilt? (List 1) (**Code F**)____

Chimanga chinayamba kufota chitakula bwanji/motani?

23. Now think about once Striga emerged.

Taganizani mmene kaufiti anamera.

a. What week (#) and month (#) did you begin seeing Striga **emerge** from the soil?____

Unali mwezi uti komanso sabata iti mmene kaufiti anayamba kumela?

b. At what physiological stage was the maize when Striga emerged?

(List 1) (**Code F)**____

Chimanga chinali chitakula bwanji/motani mmene kaufiti amaonekera?

c. Please comment on the health of maize once Striga emerged

(List up to three) (**Code G)**____

Thanzi la chimanga linali bwanji mmene kaufiti amamera?

24. Was there a cob at harvest? **Y** **N**

Chimanga chinali chili ndi tiana mmene kaufiti amamera?

a. If YES, please comment on cob size at harvest (List up to 3) (**Code G**)_______________________________________

Ngati ndi choncho, Zisononkho zinali zazikulu bwanji pa nthawi yokolola?

b. **That season,** what yield did you receive compared to others that did not have Striga (List 1) (**Code H**)__________________________

Munakolola zochuluka bwanji poyerekezera ndi zaka mmbuyomu (mmene munalibe kaufiti)?

***Note – If farmer states that all fields had Striga, ask them how their yields compared to those of their neighbors**

******Ngati mlimi wanena kuti minda yonse inali ndi kaufiti, afunseni za zokolola zawo poyerekeza ndi minda yoyandikana nayo.***

c. In addition to Striga, did you face any other challenges on this plot related to productivity?

Panalinso mavuto ena omwe anakhudza ulimi wanu kupatulapo vuto la kaufiti?

Y **N**

i. List up to 3 (**Code I**)__________________________

Section D. Methods used to address Striga

25. Enumerator (say to respondent): Now I'm going to ask you some questions about treatment practices you have heard about that control Striga. A treatment practice involves the removal of Striga once it has emerged from the soil.
Wofunsa (nenani kwa wofunsidwa): Tsopano, ndikufuna ndikufunseni mafunso okhudzana ndi njira zothana ndi kaufiti zomwe munamvapo. Njira yothana ndi kaufiti ndi iyo yomwe imatengera mlimi kuchotsa kaufiti akamera mmunda mwake.

25a. What treatment practices have you heard? (*Ndi njira ziti zothana ndi kaufiti zomwe munamvapo?)* **CODE J**	25b.When did you hear about them? (*Munazimva liti?)* **CODE K**	25c. How did you hear about them? (*Munazimva bwanji?)* **CODE L**	25d. What were the benefits you heard about? (*Munamva kuti ubwino wake ndiwotani?)* **CODE M**
i. 1st Practice	i. Years ago	i. (List up to 3)	i. (List up to 3)
ii. 2nd Practice	ii. Years ago	ii. (List up to 3)	ii. (List up to 3)
iii. 3rd Practice	iii. Years ago	iii. (List up to 3)	iii. (List up to 3)
iv. 4th Practice	iv. Years ago	iv. (List up to 3)	iv. (List up to 3)

26. Enumerator (says to respondent): Next, I would like to ask some questions about the treatment practices you have implemented. Please indicate those that you've implemented across an entire field.
Wofunsa (Nenani kwa wofunsidwa): Tsopano, ndikufuna ndikufunseni mafunso okhudzana ndi njira zothana ndi kaufiti zomwe munagwiritsapo ntchito. Muonenetsetse kuti mwatidziwitsa njira zomwe munazigwiritsa ntchito m'munda wonse.

26a. What treatment practices did you implement? *Ndi njira ziti zothana ndi kaufiti zomwe munazitsatira?* **CODE N**	26b. When did you first begin implementing them? *Munayamba kuzitsatira liti?*	26c. What did you do with the Striga? *Kaufiti amene munamuchotsayo munapanga naye chiyani?* **CODE O**	26d. What happened (in terms of Striga control and secondary benefits)? *Chinachitika n'chiyani (kumbali yoteteza kaufiti komanso ubwino wake kuposera apo)?* **CODE P**	26e. How many seasons did it take for you to see these results? *Panapita zaka zingati kuti inu muyambe kuona zotsatira?* **CODE Q**	26f.Did you stop or continue the practice after seeing these results? *Munasiya kapena kupitiriza njirazo mutaona zotsatira zakezo?*	26g. Why did you stop or continue the practice? **CODE P**
i. 1st Practice	i. Year	i. (List up to 2)	i. (List up to 3)	i.	i. Stop (0) / Continue (1)	i. (List up to 3)
ii. 2nd Practice	ii. Year	ii. (List up to 2)	ii. (List up to 3)	ii.	ii. Stop (0) / Continue (1)	i. (List up to 3)
iii. 3rd Practice	iii. Year	iii. (List up to 2)	iii. (List up to 3)	iii.	iii. Stop (0) / Continue (1)	i. (List up to 3)
iv. 4th Practice	iv. Year	iv. (List up to 2)	iv. (List up to 3)	iv.	iv. Stop (0) / Continue (1)	i. (List up to 3)

27. Enumerator (says to respondent): Also, I would like to know whom you shared the positive/negative results from implementing these practices. *Wofunsa (Nenani kwa wofunsidwa): komanso, ndimafuna nditadziwa kuti munauza ndani za zotsatira zabwino/zoipa za njira zimene munatsatirazo.*

***Note - Before asking farmers who they shared results with, transcribe the control practices they mentioned and their respective outcomes from question 26a and 26b in column 27a and 27b, respectively.**
****Musanawafunse alimi za amene anawauza za zotsatira, akumbutseni za njira zothana ndi kaufiti ndi zotsatira zake zimene azitchula mu mafunso 26a ndi 26b mu ndandanda 27a ndi 27b.***

27a. Treatment practice **(Refer to 26a)** *Njira yothana ndi kaufiti (muonere funso 26a)*	27b. List of outcomes **(Refer to 26d)** *Zotsatira (muonere funso 26b)*	27c. Who did you share these results with? *Munauzako ndani za zotsatira?* **CODE R**	27d. How many? *Munawauza zotsatira zingati?* **CODE S**
i. 1st Practice	i.1.	i.1.	i.1.
	i.2.	i.2.	i.2.
	i.3.	i.3.	i.3.
ii. 2nd Practice	ii.1.	ii.1.	ii.1.
	ii.2.	ii.2.	ii.2.
	ii.3.	ii.3.	ii.3.
iii. 3rd Practice	iii.1.	iii.1.	iii.1.
	iii.2.	iii.2.	iii.2.
	iii.3.	iii.3.	iii.3.
iv. 4th Practice	iv.1.	iv.1.	iv.1.
	iv.2.	iv.2.	iv.2.
	iv.3.	iv.3.	iv.3.

28. Enumerator (says to respondent): Finally, I want to know about the practices you haven't implemented, but would have liked to in the past or in the future.
Wofunsa (Nenani kwa wofunsidwa): Pomaliza, ndimafuna nditadziwa za njira zomwe simunathe kuzitsatira koma mukanakonda mukanatsata m'mbuyomu kapena mtsogolomu

***Note – Make sure no practice listed in column 28a was listed in 27a.**
****Wonetsetsani kuti njira zotchulidwa mu mndandanda wa mayankho a 28a zisafanane ndi njira zomwe zatchulidwa kale mu mdandanda wa mayankho a 27a.***

28a. What treatment practices would you have like to have implemented in the past, but couldn't? *Ndi njira ziti zothana ndi kaufiti mukadakonda mukadatsatira mmbuyomu koma simunathe kutero?* **CODE T**	28b. What was the reason you could not implement the treatment practice? *N'chifukwa chiyani simunathe kutsatira njira yothana ndi kaufitiyi?* **CODE U**
i. 1st Practice	i. (List up to 3)
ii. 2nd Practice	ii. (List up to 3)
iii. 3rd Practice	iii. (List up to 3)
iv. 4th Practice	iv. (List up to 3)

29. Enumerator (says to respondent): Now I would like to ask you about some practices you have heard about that prevent Striga. These practices are different from the previous ones you mentioned earlier. These practices would be implemented before you see Striga so it will not emerge from the soil in the future. There are multiple ways you can prevent Striga. Some practices you may have heard of, but are not aware of or consider them as preventative practices. These include soil fertility management practices, which improve soil texture, decrease acidity and increase nitrogen/phosphorous in the soil. Essentially, these practices enhance soil fertility. In doing so, these practices make less favorable soil conditions for Striga to spread.
Wofunsa (Nenani kwa wofunsidwa): Tsopano ndikufunsani za njira zina zomwe munamva zomwe zimateteza kaufiti mminda mwanu. Njirazi ndi zosiyana ndi zomwe mwatchula kale. Njirazi zingatsatidwe kaufiti asanamere mmunda mwathu ndi cholinga chokuti kaufitiyo asamere mtsogolomu. Pali njira zosiyanasiyana zomwe mungapewere kaufiti. Pali njira zina zoti munazimvapo, koma simukuzidziwa mmene zimatsadwira kapena kuzitenga ngati njira zopewera kaufiti. Izi ndi monga kupititsa chonde patsogolo, zomwe zimathandizira kuti nthaka isakanikilike bwino, kuchepetsa michere yowononga komanso kuonjezera Michele yomwe ili yofunikira pa kakulidwe ka mbeu zathu.chachikulu n'chakuti njirazi zimapititsa patsogolo chonde mu nthaka yathu. Potero, njirazi zimapanga nthaka yathu kuti isalore kaufiti kuti afalikire mmunda mwathu.

29a. What preventative practices have you heard? *Ndi njira ziti zopewera kaufiti zomwe munazimvapo?* **CODE V**	29b. When did you hear about them? *Munazimva liti?* **CODE W**	29c. How did you hear about them? *Munazimva kudzera mu njira yanji?* **CODE X**	29d. What were the benefits you heard about? *Ndi ubwino wanji wa njirazi umene munamva?* **CODE Y**
i. 1st Practice	i. Years ago	i. (List up to 3)	i. (List up to 3)
ii. 2nd Practice	ii. Years ago	ii. (List up to 3)	ii. (List up to 3)
iii. 3rd Practice	iii. Years ago	iii. (List up to 3)	iii. (List up to 3)
iv. 4th Practice	iv. Years ago	iv. (List up to 3)	iv. (List up to 3)
v. 5th Practice	v. Years ago	v. (List up to 3)	v. (List up to 3)
vi. 6th Practice	vi. Years ago	vi. (List up to 3)	vi. (List up to 3)

30. Enumerator (says to respondent): Next, I would like to ask some questions about some preventative practices you have implemented. Please indicate those that you've implemented across an entire field.
Wofunsa (Nenani kwa wofunsidwa): Tsopano ndikufuna ndifunse mafunso okhudzana ndi zina mwa njira zopewera kaufiti zomwe munagwiritsapo ntchito. Chonde tidziwitseni njira zomwe munazitsatira m'munda wonse.

30a. What preventative practices did you implement? *Ndi njira ziti zopewera kaufiti zomwe munagwiritsapo ntchito?* **CODE Z**	30b. When did you first begin implementing them? *Munayamba kuzigwiritsa ntchito liti?*	30c. What happened (in terms of Striga control and secondary benefits)? *Chinachitika n'chiyani (kumbali yoteteza kaufiti komanso ubwino wake kuposera apo)?* **CODE AA**	30d. How many seasons did it take for you to see these results? *Zinatengera zaka zingati kuti inu muyambe kuona zotsatira?* **CODE BB**	30e.Did you stop or continue the practice after seeing these results? *Munasiya kapena kupitiriza njirazo mutaona zotsatira zakezo?*	30f. Why did you stop or continue? *Chinachitika n'chiyani (kumbali yoteteza kaufiti komanso ubwino wake kuposera apo)?* **CODE AA**
i. 1st Practice	i. Year	i. (List up to 3)	i. (List up to 1)	i. Stop (0) / Continue (1)	i. (List up to 3)
ii. 2nd Practice	ii. Year	ii. (List up to 3)	ii. (List up to 1)	ii. Stop (0) / Continue (1)	ii. (List up to 3)
iii. 3rd Practice	iii. Year	iii. (List up to 3)	iii. (List up to 1)	iii. Stop (0) / Continue (1)	iii. (List up to 3)
iv. 4th Practice	iv. Year	iv. (List up to 3)	iv. (List up to 1)	iv. Stop (0) / Continue (1)	iv. (List up to 3)
v. 5th Practice	v. Year	v. (List up to 3)	v. (List up to 1)	v. Stop (0) / Continue (1)	v. (List up to 3)
vi. 6th Practice	vi. Year	vi. (List up to 3)	vi. (List up to 1)	vi. Stop (0) / Continue (1)	vi. (List up to 3)

31. Enumerator (says to respondent): Also, I would like to know whom you shared the positive/negative results from implementing these practices.
Wofunsa (nenani kwa wofunsidwa): Komanso, ndimafuna nditadziwa kuti munauzako ndani za zotsatira zabwino/zoipa kuchokera njira zimenezi.
***Note - Before asking farmers who they shared results with, transcribe the control practices the mentioned and their respective outcomes from question 30a and 30b in column 31a and 31b, respectively.**
****Musanafunse alimi za omwe anawauza za zotsatira, akumbutseni za njira zothana ndi kaufiti ndi zotsatira zake zomwe anatchula kale mu mafunso 30a ndi 30b komanso mu ndandanda wa 31a ndi 31b.***

31a. Preventative practice **(Refer to 30a)** *Njira zopewera kaufiti (Onerani funso 30a)*	31b. List of outcomes **(Refer to 30c)** *Ndandanda wa zotsatira (onerani funso 30b)*	31c. Who did you share these results with? *Munauza ndani za zotsatirazi?* **CODE CC**	31d. How many? *zingati?* **CODE DD**
i. 1st Practice	i.1.	i.1.	i.1.
	i.2.	i.2.	i.2.
	i.3.	i.3.	i.3.
ii. 2nd Practice	ii.1.	ii.1.	ii.1.
	ii.2.	ii.2.	ii.2.
	ii.3.	ii.3.	ii.3.
iii. 3rd Practice	iii.1.	iii.1.	iii.1.
	iii.2.	iii.2.	iii.2.
	iii.3.	iii.3.	iii.3.
iv. 4th Practice	iv.1.	iv.1.	iv.1.
	iv.2.	iv.2.	iv.2.
	iv.3.	iv.3.	iv.3.
v. 5th Practice	v.1.	v.1.	v.1.
	v.2.	v.2.	v.2.
	v.3.	v.3.	v.3.
vi. 6th Practice	vi.1.	vi.1.	vi.1.
	vi.2.	vi.2.	vi.2.
	vi.3.	vi.3.	vi.3.

32. More specifically, I would like to know where you receive your inputs from to complete the preventative practices you mentioned.
Makamaka, ndimafuna nditadziwa kuti zipangizo za ulimi zomwe munagwiritsa ntchito popewa kaufiti munazipeza kuti?
***Note - Before asking farmers about the sources of their inputs, transcribe the control practices they mentioned from question 31a in column 32a.**
****Musanafunse alimi za kumene anapeza zipangizo zawo, akumbutseni za njira zopewera zimene anatchula mu mafunso 31a mu ndandanda was 32a.***

32a. Preventative practice **(Refer to 31a)** *Njira zopewera Kaufiti 31a*	32b. Week & Month *Sabata ndi mezzo*	32c. Specify crop if rotation/ intercropping listed *Tchulani mbeu ngati mwayidzala mwa kasinthasintha kapena kasakaniza* **CODE EE**	32d. Specify seed source if rotation/ intercropping listed *Mundiuze za kumene munapeza mbeu (ngati kasinthasintha/kasakaniza zatchulidwa)* **CODE FF**	32e. Specify type of fertilizer or manure if fertilizer/ manure application was listed *Mundiuze mtundu wa fetereza kapena manyowa (ngati fetereza/manyowa zatchulidwa)* **CODE GG**	32f. Specify source of fertilizer or manure if fertilizer/ manure application was listed *Mundiuze za kumene munapeza fetereza/manyowa (ngati zinatchulidwa)* **CODE HH**	32g. How was the fertilizer/ manure incorporated? *Fetereza/ manyowa anathiridwa motani?* **CODE II**
i. 1st practice	i.1. Week # i.2. Month #	i. (List up to 3)	i. (List up to 3)	i. (List up to 3)	i. (List up to 3)	i.1. Degraded Y N i.2. (List up to 2)
ii. 2nd practice	ii.1. Week # ii.2. Month #	ii. (List up to 3)	ii. (List up to 3)	ii. (List up to 3)	ii. (List up to 3)	ii.1. Degraded? Y N ii.2. (List up to 2)
iii. 3rd practice	iii.1. Week # iii.2. Month #	iii. (List up to 3)	iii. (List up to 3)	iii. (List up to 3)	iii. (List up to 3)	iii.1. Degraded? Y N iii.2. (List up to 2)
iv. 4th practice	iv.1. Week # iv.2. Month #	iv. (List up to 3)	iv. (List up to 3)	iv. (List up to 3)	iv. (List up to 3)	iv.1. Degraded? Y N iv2. (List up to 2)
v. 5th practice	v.1. Week # v.2. Month #	v. (List up to 3)	v. (List up to 3)	v. (List up to 3)	v. (List up to 3)	v.1. Degraded? Y N v.2. (List up to 2)
vi. 6th practice	vi.1. Week # vi.2. Month #	vi. (List up to 2)	vi. (List up to 3)	vi. (List up to 3)	vi. (List up to 3)	vi.1. Degraded? Y N vi.2. (List up to 2)

33. Enumerator (says to respondent): I want to know about the practices you haven't implemented, but would have liked to in the past or in the future.
Wofunsa (Nenani kwa wofunsidwa): Pomaliza, ndimafuna nditadziwa za njira zimene simunathe kuzitsatira, koma mukanakonda mutazitsatira.
***Note – Make sure no practice listed in column 32a was listed in 33a.**
****Wonetsetsani kuti njira zatchulidwa mu ndandanda 32a zisafanane ndi zimene zatchulidwa mu 33a.***

33a. What preventative practices would you have like to have implemented in the past, but couldn't? *Ndi njira ziti zopewera kaufiti zomwe mukadakonda mutazitsata m'mbuyomu koma simunathe kutero?* **CODE JJ**	33b. Specify type of manure or fertilizer if farmer mentioned manure/ fertilizer application *Mundiuze mtundu wa fetereza kapena manyowa (ngati fetereza/manyowa zatchulidwa)* **CODE KK**	33c. Specify seed if farmer mentioned intercropping/crop rotation *Tchulani mtundu wa mbeu (ngati mlimi watchula mbeu)* **CODE LL**	33d. What was the reason you could not implement the preventative practice? Ndi chifukwa chiyani munakanika kutsatira njira yopewera kaufiti? **CODE MM**
i. 1st Practice	i. (List up to 2)	i. (List up to 2)	i. (List up to 3)
ii. 2nd Practice	ii. (List up to 2)	ii. (List up to 2)	ii. (List up to 3)
iii. 3rd Practice	iii. (List up to 2)	iii. (List up to 2)	iii. (List up to 3)
iv. 4th Practice	iv. (List up to 2)	iv. (List up to 2)	iv. (List up to 3)
v. 5th Practice	v. (List up to 2)	v. (List up to 2)	v. (List up to 3)
vi. 6th Practice	vi. (List up to 2)	vi. (List up to 2)	vi. (List up to 3)

34. Enumerator (says to respondent): Finally, I would like to know about some soil fertility practices you implemented before Africa RISING arrived. Please indicate those that you've implemented across an entire field.
Wofunsa (Nenani kwa wofunsidwa): Tsopano ndikufuna ndifunse mafunso okhudzana ndi zina mwa njira zopewera kaufiti zomwe munagwiritsapo ntchito. Chonde tidziwitseni njira zomwe munazitsatira m'munda wonse.

34a. What soil fertility practices did you implement? *Ndi njira ziti zopewera kaufiti zomwe munagwiritsapo ntchito?* **CODE JJ**	34b. How did you hear about them? *Munazimva kudzera mu njira yanji?* **CODE X**	34c. When did you hear about them *Sabata ndi mwezi?*	34d. After hearing about them, how long did it take until you fully implemented them across an entire field?
i. 1st Practice	i. (List up to 3)	i. Year	i. Years
ii. 2nd Practice	ii. (List up to 3)	ii. Year	ii. Years
iii. 3rd Practice	iii. (List up to 3)	iii. Year	iii. Years
iv. 4th Practice	iv. (List up to 3)	iv. Year	iv. Years
v. 5th Practice	v. (List up to 3)	v. Year	v. Years
vi. 6th Practice	vi. (List up to 3)	vi. Year	vi. Years

Section E. Food and labor preferences

Enumerator (says to respondent): I'm going to present to you several scenarios where you have to choose between cultivating a monoculture of maize or another cropping system across **1 ha**.
Wofunsa (Nenani kwa wofunsidwa): Tsopano ndikuyerekezerani njira zingapo zosiyanasiyana ndipo mukuyenera kusankhapo imodzi pakati pa kalimidwe ka chimanga pachokha kapena kalimidwe ka mtundu wina pa munda wokwana hekitala imodzi.

35. Enumerator (says to respondent): Suppose you have the choice of accepting 20 (50kg) bags of traditional maize (Option A) or a less amount of early-maturing maize (Option B). There is a chance you may not be able to receive 20 bags of traditional maize. With the early maturing maize, however, you will receive the specified amount (e.g., 15 bags) without a chance of losing it to Striga.
Wofunsa (Nenani kwa wofunsidwa): Tingoyerekeza mwapatsidwa mwayi wolandira matumba 20 (a 50kg) a chimanga cha makolo (chisankho A) kapena chimanga chocheperapo koma chocha msanga (chisankho B).
***Note- Do NOT show this table to the farmer. You will present the choices in an iterative manner. State the first tradeoff (e.g., "Would you take a sure-yield of 15 bags of early maturing maize/ha or try for 20 bags/ha of traditional maize?"). If they do not select the first choice, then present T2.**
******Musaonetse zimene mukufunsazi kwa mlimi. Mudzifunsa zisankhozi polankhulana basi. Tchulani kasinthanitsa woyamba (mwachitsanzo, Mungatenge zokolola zotsimikizika zokwana matumba 15 a chimanga chocha msanga pa hekitala kapena mungafune matumba 20 pa hekitala a chimanga cha makolo?). Ngati sasankha chisankho choyamba, afunseni kasinthanitsa T2***

Choice	Option A *Chisankho A* (Traditional Maize) (*Chimanga cha makolo)*	Option B *Chisankho B* (Early-maturing maize) *(Chimanga chocha msanga)*
T1	☐ 20 Bags	☐ 15 Bags
T2	☐ 20 Bags	☐ 16 Bags
T3	☐ 20 Bags	☐ 17 Bags
T4	☐ 20 Bags	☐ 18 Bags
T5	☐ 20 Bags	☐ 19 Bags
T6	☐ 20 Bags	☐ 20 Bags

If Option B was not chosen, how many bags would it take for them to switch:________
Ngati B wasankhidwa, zatengera matumba angati m'chaka choyamba kuti mlimi asinthe maganizo:______

36. Suppose you have the choice of accepting 20 (50kg) bags of traditional maize **for each season for two years** (Option A) or a larger amount of food in if you **intercrop** pigeon pea and maize within the same field (Option B). For each of the six choice sets presented, check the box for the option you prefer?
Tingoyerekeza mwapatsidwa mwayi wolandira matumba 20 (a 50 kg) a chimanga cha makolo m'chaka chilichonse kwa zaka ziwiri (chisankho A) kapena matumba ochulukirapo a chakudya mu chaka choyamba kapena chachiwiri ngati mungalime chimanga ndi nandolo mwa kasakaniza m'munda womwewo (Chisankho B). Pa chisankho chilichonse mwa zisankho zisanu n'chimodzi, chongani mu bokosi lomwe likusonyeza chisankho cha mlimi.
****Note – Emphasize that both crops are planted simultaneously, but pigeon pea matures later into the season once the farmers have harvested maize.***
Tsimikirani mfundo yokuti mbeu zonsezo zimadzalidwa pa kamodzi, koma kaufiti amakhwima mochedwerapo alimi atakolora kale chimanga.

Choice	Option A (Maize Monoculture)	Option B (Maize-Pigeon Pea Intercrop)
T1	☐ 20 Maize Bags	☐ 15 Maize Bags + 7 Pigeon Pea Bags
T2	☐ 20 Maize Bags	☐ 16 Maize Bags + 7 Pigeon Pea Bags
T3	☐ 20 Maize Bags	☐ 17 Maize Bags + 7 Pigeon Pea Bags
T4	☐ 20 Maize Bags	☐ 18 Maize Bags + 7 Pigeon Pea Bags
T5	☐ 20 Maize Bags	☐ 19 Maize Bags + 7 Pigeon Pea Bags
T6	☐ 20 Maize Bags	☐ 20 Maize Bags + 7 Pigeon Pea Bags

If Option B was chosen, how many bags in year one, would it take for them to switch:___________
Ngati B wasankhidwa, zatengera matumba angati m'chaka choyamba kuti mlimi asinthe maganizo:______

37. Suppose you have the choice of accepting 20 (50kg) bags of traditional maize **for each season for two years** (Option A) or a larger amount of maize in a **second season** if you cultivate sole soybean the first year (Option B). For each of the six choice sets presented, check the box for the option you prefer?
Tingoyerekeza mwapatsidwa mwayi wolandira matumba 20 (a 50 kg) a chimanga cha makolo m'chaka chilichonse kwa zaka ziwiri kapena matumba ochulukirapo a chimanga mu chaka chachiwiri ngati mungalima soya payekha m'chaka choyamba. Pa chisankho chilichonse mwa zisankho zisanu n'chimodzi, chongani mu bokosi lomwe likusonyeza chisankho cha mlimi.

Choice	Option A *Chisankho A* (Maize 1st Season -> Maize 2nd Season)	Option B *Chisankho B* (Soybean 1st Season -> Maize 2nd season)
T1	☐ 20 Maize -> 20 Maize Bags	☐ 30 Soybean -> 26 Maize Bags
T2	☐ 20 Maize -> 20 Maize Bags	☐ 30 Soybean -> 28 Maize Bags
T3	☐ 20 Maize -> 20 Maize Bags	☐ 30 Soybean -> 30 Maize Bags
T4	☐ 20 Maize -> 20 Maize Bags	☐ 30 Soybean -> 32 Maize Bags
T5	☐ 20 Maize -> 20 Maize Bags	☐ 30 Soybean -> 34 Maize Bags
T6	☐ 20 Maize -> 20 Maize Bags	☐ 30 Soybean -> 36 Maize Bags

If Option B was not chosen, how many bags in year two, would it take for them to switch:________
Ngati B wasankhidwa, zatengera matumba angati m'chaka choyamba kuti mlimi asinthe maganizo:______

38. Suppose you have the choice of accepting 20 (50kg) bags of traditional maize **for a single season** (Option A) or a larger amount of food in **one season** if you **intercrop** cowpea and maize within the same field (Option B). For each of the six choice sets presented, check the box for the option you prefer?
Tingoyerekeza mwapatsidwa mwayi wolandira matumba 20 (a 50 kg) a chimanga cha makolo kwa chaka chimodzi (chisankho A) kapena matumba ochulukirapo a chakudya ngati mungalime chimanga ndi khobwe mwa kasakaniza m'munda womwewo (Chisankho B). Pa chisankho chilichonse mwa zisankho zisanu n'chimodzi, chongani mu bokosi lomwe likusonyeza chisankho cha mlimi.

Choice	Option A (Maize 1st Season -> Maize 2nd Season)	Option B (Intercrop 1st Season
T1	☐ 20 Maize Bags	☐ 15 Maize + 6 Cowpea Bags
T2	☐ 20 Maize Bags	☐ 16 Maize + 6 Cowpea Bags
T3	☐ 20 Maize Bags	☐ 17 Maize + 6 Cowpea Bags
T4	☐ 20 Maize Bags	☐ 18 Maize + 6 Cowpea Bags
T5	☐ 20 Maize Bags	☐ 19 Maize + 6 Cowpea Bags
T6	☐ 20 Maize Bags	☐ 20 Maize + 6 Cowpea Bags

If Option B was not chosen, how many bags in year one, would it take for them to switch:________
Ngati B wasankhidwa, zatengera matumba angati m'chaka choyamba kuti mlimi asinthe maganizo:______

39. Suppose you have the choice of accepting 20 (50kg) bags of traditional maize (Option A) from weeding twice or a larger amount for more labor, not tilling the land and reserving maize residues for mulching the next season (Option B). More labor would entail three weedings as well as cutting **and** applying crop residues prior to sowing maize. For each of the six choice sets presented, check the box for the option you prefer?
Tingoyerekeza mwapatsidwa mwayi wolandira matumba 20 (a 50 kg) a chimanga cha makolo chifukwa chopalira kawiri (chisankho A) kapena matumba ochulukirapo chifukwa cha ntchito yochulukirapo (chisankho B). Ntchito yochulukirapo ikutanthauza kupalira katatu komanso kuthira manyowa mmudza tisanadzale chimanga. Pa chisankho chilichonse mwa zisankho zisanu n'chimodzi, chongani mu bokosi lomwe likusonyeza chisankho cha mlimi.

Choice	Option A *Chisankho A* (2 Weedings)	Option B *Chisankho B* (3 Weedings + No Till + Crop Residue App.)
T1	☐ 20 Maize -> 20 Maize Bags	☐ 20 Bags -> 21 Maize Bags
T2	☐ 20 Bags -> 20 Maize Bags	☐ 20 Bags -> 22 Maize Bags
T3	☐ 20 Bags -> 20 Maize Bags	☐ 20 Bags -> 23 Maize Bags
T4	☐ 20 Bags -> 20 Maize Bags	☐ 20 Bags -> 24 Maize Bags
T5	☐ 20 Bags -> 20 Maize Bags	☐ 20 Bags -> 25 Maize Bags
T6	☐ 20 Bags -> 20 Maize Bags	☐ 20 Bags -> 26 Maize Bags

If Option B was not chosen, how many bags in year two, would it take for them to switch:________
*Ngati B wasankhidwa, zatengera matumba angati m'chaka choyamba kuti mlimi asinthe maganizo:*______

40. Suppose you have the choice of accepting 20 (50kg) bags of traditional maize (Option A) or a larger amount by applying herbicide (Option B). Option A comes with enough fertilizer for a 1-acre field to receive 20 bags. Option B comes with a sprayer and enough herbicide to apply across a 1-acre field. For each of the six choice sets presented, check the box for the option you prefer?
Tingoyerekeza mwapatsidwa mwayi wolandira matumba 20 (a 50 kg) a chimanga cha makolo (Chisankho A) kapena matumba ochulukirapo pothira mankhwala opha tchire mmunda (Chisankho B). Chisankho A chikubwera ndi matumba a fetereza wokwanira kuthira munda wa 1 acre kuti mudzapate matumba 20. Chisankho B chikubwera ndi sprayer komanso mankhwala opha tchire okwanira kuthira m'munda wa 1 acre. Pa chisankho chilichonse mwa zisankho zisanu n'chimodzi, chongani mu bokosi lomwe likusonyeza chisankho cha mlimi.

Choice	Option A *Chisankho A*	Option B *Chisankho B*

	(2 Weedings + 1 Fertilizer)	(No Weeding + Herbicide)
T1	☐ 20 Bags	☐ 21 Bags
T2	☐ 20 Bags	☐ 22 Bags
T3	☐ 20 Bags	☐ 23 Bags
T4	☐ 20 Bags	☐ 24 Bags
T5	☐ 20 Bags	☐ 25 Bags
T6	☐ 20 Bags	☐ 26 Bags

If Option B was not chosen, how many bags would it take for them to switch:________
Ngati B wasankhidwa, zatengera matumba angati m'chaka choyamba kuti mlimi asinthe maganizo:______

41. Suppose you have the choice of accepting 20 (50kg) bags of traditional maize (Optio A) or larger amount by applying herbicide (Option B). Option A will cost 31,250MKW for 25kgs of seed. You will not ba able to apply fertilizer. Optoin B will cost 31,250 for seed, 20,000 for a sprayer and 3,650 for herbicide. So Option A will cost 31,250 and Option B will cost 54,900MW. For each of the six choice sets presented, chock the box for the option you prefer.
Tingoyerekeza mwapatsidwa mwayi wolandira matumba 20 (a 50 kg) a chimanga cha makolo (Chisankho A) kapena matumab ochulukirapo a chimanga pothira mankhwala opha tchire mmunda (Chisankho B). Chisankho A chikutengerani MK 31,250 pogula mbeu yokwana 25kg. Simukyenera kuthira fetereza. Chisankho B mugwiritsa Ntchito MK31,250 kugulira mbeu, MK20,000 kugulira sprayer komanso MK3,650 kugulira mankhwala okupha tchire ndipo chisankho B ndalama YOnse pamodzi ikuwana MK54,900. Pa chisankho chilchonse mwa zisankho zisanu n'chimodzi, chongani mu bokosi lomwe likusonyeza chisankho cha mlimi.

Choice	Option A *Chisankho A* (No Herbicide)	Option B *Chisankho B* (Herbicide)
T1	☐ 20 Bags	☐ 22 Bags
T2	☐ 20 Bags	☐ 24 Bags
T3	☐ 20 Bags	☐ 26 Bags
T4	☐ 20 Bags	☐ 28 Bags
T5	☐ 20 Bags	☐ 30 Bags
T6	☐ 20 Bags	☐ 32 Bags

If Option B was not chosen, how many bags in would it take for them to switch:________

*Ngati B wasankhidwa, zatengera matumba angati m'chaka choyamba kuti mlimi asinthe maganizo:*______

Section F. Debriefing

Question	Answer (CODE NN)
Enumerator Assessment of Data Quality/Farmers Ability to Recall Information	
Time to complete questionnaire	

Code A

1. Red flowers *(maluwa ofiila)*
2. Yellow flowers *(maluwa a chikasu)*
3. Pink flowers *(maluwa ofiilirako)*
4. Small red roots *(timizu tofiila)*
5. It grows underground unlike an annual *(maka uyo yekhayo amakulira pansi pa nthaka osaonekera)*
6. Tiny thin leaves (spike leaf arrangement)
7. White roots
8. Grows on maize plant
9. Smaller/thinner than annual weeds

99. Other (specify) (*Zina [tchulani])*

Code B

1. No yield vs some yield *(osakolora kalikonse kapena kukolora zochepa kwambiri)*
2. ¼ of what you would receive (*limodzi mwa ma gawo anayi a zimene mumayembekezera [quarter])*
3. ½ of what you would receive (*theka la zimene mumayembekezera)*
4. ¾ of what you would receive (*magawo atatu mwa anayi a zomwe mumayembekezera)*
5. Short/stunted (*chachifupi/chokwinimbira)*
6. Skinny/thin (*choonda/toonda)*
7. Wilting
8. Poor germination
9. Cob formed early (before maize plant was fully grown) *chimanga chimabereka mwamsanga (cgisanakule)*

99. Other (specify) (*Zina [tchulani])*

Code C

1. Maize wilts even though there is water *(Chimanga chimafota ngakhale pamakhala pali chinyontho)*
2. Maize wilts even though there is fertilizer *(chimanga chimafota ngakhala pamakhala pathiridwa fetereza)*
3. Maize wilts before 2nd weeding *(chimanga chomafota tisanapalire kachiwiri)*
4. Tassle forms early (before maize plant is fully grown) *chimanga chimamasula mwamsanga (chisanakule)*
5. Cob forms early (before maize plant is fully grown) *chimanga chimabereka mwamsanga (cgisanakule)*
6. Yellowing of leaves
7. Stunted growth/early maturity
8. Thin maize stalk
9. Poor germination

99. Other (specify) (*Zina [tchulani])*

Code D

1. Removes nutrients from soil *(amachotsa chakudya cha mu nthaka)*
2. Removes water from soil *(amachotsa madzi mu nthaka)*
3. Poisons roots *(mizu yake ndi poizoni/chiphe)*
4. Attaches to roots *(amamera pa mizu inzake)*
5. Removes water from plant *(amamwa madzi mu zomera zathu)*
6. Removes nutrients from plant. *(amayamwa chakudya kuchoka mu zomera zathu)*
7. Harbors pests

99. Other (specify) (*Zina [tchulani])*

CODE E

1. Heavy infestation of non-Striga weeds (*lochuluka chire losakhala kaufiti)*
2. Acidic soil (*la mchere wa acid)*
3. Sandy soil (*la mchenga)*
4. Little to no soil organic matter (manure) (*popanda chonde chokwanira [manyowa])*
5. Eroded soil (*nthaka yokokololoka)*
6. Low fertility (*Fetereza wosakwanira)*
7. Water logging/hard pan (*la madzi ochuluka)*
8. Iron/red soil
9. Hard pan (clay soil)

99. Other (specify) (*Zina [tchulani])*

CODE F

1. Before tasseling *(chisanamasule)*
2. At tasseling *(chitamasula)*
3. Before you see the cob but after tasseling *(chitamasula*
4. Once cob appears *(chitabereka tiana)*
5. Once cobs have reached full maturity *(chimanga chitakhwima)*

99. Other (specify) (*Zina [tchulani])koma chisanabereke ana)*

CODE G

1. Short/stunted plant (*chachifupi/chokwinimbira)* | Short/stunted cob
2. Skinny/thin (*choonda/toonda)* | Skinny/thin cob
3. Poor Germination (*sizinamere bwino)*
4. Maize leaves turn purple (*Masamba a chimanga amasanduka mtundu wa purple)*
5. Maize leaves turn yellow (*Masamba a chimanga amasanduka mtundu wa chikasu)*
6. Maize leaves turn brown before harvest (early leaf senescence) (*Masamba a chimanga amasanduka mtundu wotuwa chisanakoloredwe [masamba amauma msanga])*
7. Early maturity (bearing cob before fully grown)

99. Other (specify) (*Zina [tchulani])*

CODE H

1. Normal/no difference (*zabwinobwino)*
2. ¼ of what you would receive (*limodzi mwa ma gawo anayi a zimene mumayembekezera [quarter])*
3. ½ of what you would receive (*theka la zimene mumayembekezera)*
4. ¾ of what you would receive (*magawo atatu mwa anayi a zomwe mumayembekezera)*
5. Basically nothing
6. 1/3 of what you would receive
99. Other (specify) (*Zina [tchulani])*

CODE I

0. None
1. Erosion *Kukokoloka kwa nthaka*
2. Drought *ng'amba*
3. Lack of fertilizer *kusowa kwa fetereza*
4. Lack of compost, manure, mulch, etc.,
5. Soil acidity *mchere wa mu dothi*
6. Low soil fertility *kuchepa kwa chonde mu nthaka*
7. Waterlogging
8. Pests, disease *tizilombo, matenda*
9. Lack of seed
10. Annual weed pressure; too many weeds
11. Flooding
12. Termites
13. Lodging
14. Lack of labor
15. Illness
99. Other (specify) (*Zina [tchulani])*

CODE J

0. Nothing
1. Kupalira (scraping)
2. Kuzulira atapanga maluwa (uprooting after flowering)
3. Kuzulira asanapange maluwa (before flowering)
4. Kusenda/Kuojekera (cover weeds with soil)
5. Kubandira (banking)
6. Herbicide (*Mankhwala wopha tchire)*
7. Deep tillage (*kulima mozama/mwakuya)*
8. Point manure application (*Kuika manyowa pa phando lodzalira)*
9. Burning affected area
10. Point fertilizer application
11. Point manure application
12. Point maize bran application
13. Point ash application
14. Remove and bury in a deep pit
99. Other (specify) (*Zina [tchulani])*

CODE K

1. 0-2
2. 3-5
3. 6-10
4. 10+

CODE L

1. NGO/Inter. Org. (*Mabungwe wosakhala a boma)*
2. Radio (*Wailesi)*
3. Poster/Hand Out (*Postala/zojambulidwa pa pepala)*
4. Demonstration trial (*Munda wachionetsero)*
5. Extension agent (*Alangizi)*
6. Market (*Ku msika)*
7. Experimentation (*Kuyeselera/kafukufuku*)
8. Neighbor/Farmer (*Wokhala moyandikana naye/mlimi)*
9. Farmer group/coop (*ku gulu/bungwe la alimi)*
10/14. Family, relatives
11. Tradition *Za makolo*
12. Agro-dealer (*Wogulitsa zipangizo za ulimi)*
13. Intuition (*Kungopanga poganiza kuti ndizotheka)*
15. School
99. Other (specify) (*Zina [tchulani])*

CODE M

1. Striga would come back **less in short term** (same season) (*Kaufiti anameranso pasanadutse nthawi yaitali)*
2. Striga would come back **less in the long term** (next season) (*Kaufiti anameranso koma wochepa [m'chaka chotsatira])*
3. Striga would not come back at all (*Kaufiti sanamerenso)*
4. Soil fertility would increased (*Chonde chimaonjezereka)*
5. Biomass for fuel or fodder would increase (*Mapesi amachuluka)*
6. Maize yield would **increase in the short term** (same season) (*Zokolora zimachuluka m'chaka chimenecho)*
7. Maize yield would **increase in the long term** (next season) (*Zokolola zimachuluka m'chaka chotsatira)*
8. Aggregate food production would increase (*Chakudya chimachuluka)*
9. Pest incidence would decrease (*Tizilombo toononga mbeu timachepa)*
10. Profit (from on-farm production) would increase (*Phindu [purofiti] lochokera ku zokolola zathu limachuluka)*
11. On-farm labor would decrease (*Ntchito yogwira pamundapo imachepa)*
12. Overall weed pressure decreased
13. Delayed Striga emergence
14. Improved water retention/soil moisture holding capacity
15. Reduced erosion; improved soil structure/texture
16. Sustained Striga control; prevented Striga problem from getting worse
99. Other (specify) (*Zina [tchulani])*

CODE N

0. None
1. Kupalira (scraping)
2. Kuzulira atapanga maluwa (uprooting after flowering)
3. Kuzulira asanapange maluwa (before flowering)
4. Kusenda/Kuojekera (cover weeds with soil)
5. Kubandira (banking)
6. Herbicide (*Mankhwala wopha tchire)*
7. Deep tillage (*kulima mozama/mwakuya)*
8. Point manure application (*Kuika manyowa pa phando lodzalira)*
9. Burning
10. Point fertilizer application
11. Point manure/fertilizer mix application
12. Point maize bran application
13. Point ash application
14. Remove and bury in a deep pit
99. Other (specify) (*Zina [tchulani])*

CODE Q

0. The same season (*Chaka chomwecho)*
1. The following season (*Chaka chotsatira)*
2. The following 2 seasons (*Patatha zaka ziwiri)*
3. The following 3-5 seasons (*patatha zaka zitatu kufikira zisanu)*
4. The following 6-10 seasons (*patatha zaka chisanu n'chimodzi kufikira khumi)*
5. The following 10+ seasons (*Patatha zaka zoposera khumi)*
99. Other (specify) (*Zina [tchulani])*

CODE O

0. Nothing (*Palibe)*
1. Burn (*Kuyatsa)*
2. Incorporate into ridge (*Kumukwilira mu mzere)*
3. Put in furrow (*Kumuika mu khwawa)*
4. Remove from field (*Kumutaya kunja kwa munda)*
5. Consumed/Fed to livestock (*Kudya/kudyetsera ku ziweto)*
6. Bury in a deep pit
99. Other (specify) (*Zina [tchulani])*

CODE P

0. None/no change

<u>*(positive) Ubwino wake*</u>

1. Striga came back **less in short term** (same season) (*Kaufiti anemeranso koma wocheperapo m'chaka chomwecho)*
2. Striga came back **less in the long term** (next/multiple season/s) (*Kaufiti anameranso koma wocheperapo patapita nthawi [chaka/zaka] zotsatira)*
3. Striga did not come back at all that season (same season) (*Kaufiti sanamerenso m'chaka chimenecho)*
4. Soil fertility increased (*chonde chinaonjezereka mu nthaka)*
5. Increased biomass for fuel or fodder (*mapesi wochuluka omwe anagwira ntchito ngati nkhuni kapena chakudya cha ziweto)*
6. Maize yield **increased in the short term** (same season) (*zokolola chimanga zinachuluka m'chaka chomwecho)*
7. Maize yield **increased in the long term** (next season) (*Zokolola zinachuluka m'chaka chotsatira)*
8. Aggregate food production increased *Chakudya (chonse tikachiphatikiza chinachuluka)*
9. Pest incidence reduced (*tizilombo toononga mbeu tinachepa)*
10. Profit (from on-farm production) increased *(Phindu [purofiti] lochokera ku zokolola zathu linachuluka)*
11. On-farm labor decreased (*Ntchito yogwira pamundapo inachepa)*

<u>*(negative) kuipa kwake*</u>

12. Striga came back **more in short term** (same season) (*Kaufiti anameranso m'chaka chomwecho koma wochulukirapo)*
13. Striga came back **more in the long term** (next season) (*Kaufiti anameranso wochuluka m'chaka chotsatira)*
14. Maize yield **decreased in the short term;** harvested little (same season) (*Zokolora zinachepa m'chaka chimenecho)*
15. Maize yield **decreased in the long term;** harvested little (next season) (*zokolola chimanga zinachepa m'chaka chotsatira)*
16. Aggregate food production decreased (*Chakudya chonse tikachiphatikiza chinachepa)*
17. Pest incidence increased; harbored pests (*Tizilombo toononga mbeu tinachuluka)*

18 Profit (from on-farm production) decreased (*Phindu [purofiti] lochokera ku zokolola zathu linachepa)*

19. On-farm labor increased (*Ntchito yogwira pamundapo inachuluka)*
20. Inputs became unavailable (*zipangizo zogwilira ntchito ya ulimi zinasowa)*
21. Inputs became too expensive (*zipangizo zogwilira ntchito ya ulimi zinakwera mtengo)*
22. Delayed Striga emergence
23. Reduced overall weed pressure
24. Improved water retention/soil moisture holding capacity
25. Reduced erosion/Improved soil structure/texture
26. Sustained Striga emergence; prevented Striga problem from getting worse
27. Damaged soil

99. Other (specify) (*Zina [tchulani])*

CODE R

0. None/nobody
1. Neighbor/Farmer (*Wokhala moyandikana naye/mlimi)*
2. Farmer group/coop (*ku gulu/bungwe la alimi)*

specify) (*Zina [tchulani])*

3. NGO/Inter. Org. (*Mabungwe wosakhala a boma)*
4. Agro-dealer (*Wogulitsa zipangizo za ulimi)*
5. Family, relatives

99. Other (specify) (*Zina [tchulani])*

CODE S

0. None (*Palibe)*
1. 0-5
2. 5-10
3. 10-15
4. 15-20
5. +20

CODE T

1. Kupalira (scraping)
2. Kuzulira atapanga maluwa (uprooting after flowering)
3. Kuzulira asanapange maluwa (before flowering)
4. Kusenda/Kuojekera (cover weeds with soil)
5. Kubandira (banking) *tchire)*
6. Herbicide (*Mankhwala wopha*
7. Deep tillage (*kulima mozama/mwakuya)*
8. Point manure application (*Kuika manyowa pa phando lodzalira)*
9. Burning
10. Point fertilizer application
11. Point manure/fertilizer mix application
12. Point maize bran application
13. Point ash application
14. Remove and bury in a deep pit

99. Other (specify) (*Zina [tchulani]) [tchulani])*

CODE U

1. No time *Analibe mpata (nthawi)*
2. Shortage of household labor (*Kuchepa kwa wogwira ntchito panyumba)*
3. Could not hire outside labor (*Sakanakwanitsa kulemba a ganyu)*
4. Illness/death in family (*Matenda/Maliro wokhudza banja)*
5. Rain (*Mvula)*
6. Market price for outputs (e.g., legume grain) was too low (*Mitengo ya zokolola (mwachitsanzo, mbeu za gulu la nyemba) inali yotsika kwambiri)*
7. Ganyu labor took away from practice (*Aganyu anatsata njira ina osakhala imene anauzidwa)*
8. Could not afford inputs (*Sindikadakwanitsa kupeza zipangizo zotsatilira njirayi)*
9. Input availability (*Kapezekedwe ka zipangizo)*
10. Did not know; Not enough information/training (*samadziwa za mmene ndingatsatire njirayi; sanaphunzitsidwe/sanapatsidwe upangiri)*

99. Other (specify) (*Zina [tchulani])*

CODE V

1. Crop rotation (*Kulima mwa kasinthasintha)*
2. Manure application (*Kuthira Manyowa)*
3. Early yielding variety (*Kubzala mbeu zocha msanga)*
4. Fertilizer application (*Kuthira fetereza)*
5. Legume crop residue mulch (*Kuphimbira ndi masangwi a mbeu zathu za mgulu la nyemba)*
6. Maize crop residue mulch *(Kuphimbira ndi mapesi a chimanga)*
7. Intercropping (*Kulima mwa kasakaniza)*
8. Minimum tillage (*mtayakhasu)*
9. Deep tillage (*Kulima mozama/mokuya)*
10. Pre-emergence herbicide (*kuthira mankhwala okupha tchire [wothira mbeu zisanamere]*
11. Maize residue incorporation
12. Legume residue incorporation
13. Maize + legume residue mix incorporation
14. Tobacco pellet application
15. Maize bran application
16. Ash application
17. Planting leguminous trees (e.g., tephrosia)
99. Other (specify) (*Zina [tchulani])*

CODE W

1. 0-2
2. 3-5
3. 6-10
4. 10+

CODE X

1. NGO/Inter. Org. (*Mabungwe wosakhala a boma)*
2. Radio (*Wailesi)*
3. Poster/Hand Out (*Postala/zojambulidwa pa pepala)*
4. Demonstration trial (*Munda wachionetsero)*
5. Extension agent (*Alangizi)*
6. Market (*Ku msika)*
7. Experimentation (*Kuyeselera/kafukufuku*)
8. Neighbor/Farmer (*Wokhala moyandikana naye/mlimi)*
9. Farmer group/coop (*ku gulu/bungwe la alimi)*
10 or 14. Family, relatives
11. Tradition *Za makolo*
12. Agro-dealer (*Wogulitsa zipangizo za ulimi)*
13. Intuition (*Kungopanga poganiza kuti ndizotheka)*
15. School
99. Other (specify) (*Zina [tchulani])*

CODE Y

1. Striga came back **less in short term** (same season) (*Kaufiti anemeranso koma wocheperapo m'chaka chomwecho)*
2. Striga came back **less in the long term** (next/multiple season/s) (*Kaufiti anameranso koma wocheperapo patapita nthawi (chaka/zaka zotsatira)*
3. Striga did not come back at all that season (same season) (*Kaufiti sanamerenso m'chaka chimenecho)*
4. Soil fertility increased (*chonde chinaonjezereka mu nthaka)*
5. Increased biomass for fuel or fodder (*mapesi wochuluka omwe anagwira ntchito ngati nkhuni kapena chakudya cha ziweto)*
6. Maize yield **increased in the short term** (same season) (*zokolola (chimanga) zinachuluka m'chaka chomwecho)*
7. Maize yield **increased in the long term** (next season) (*Zokolola zinachuluka m'chaka chotsatira)*
8. Aggregate food production increased *Chakudya (chonse tikachiphatikiza) chinachuluka*
9. Pest incidence reduced (*tizilombo toononga mbeu tinachepa)*
10. Profit (from on-farm production) increased *(Phindu [purofiti] lochokera ku zokolola zathu linachuluka)*
11. On-farm labor decreased (*Ntchito yogwira pamundapo inachepa)*
12. Delayed Striga emergence
13. Decreased overall weed pressure
14. Improved water retention/soil moisture holding capacity
15. Reduced erosion; improved soil structure/texture
16. Sustained Striga emergence; prevented Striga problem from getting worse
99. Other (specify) (*Zina [tchulani])*

CODE Z 0. None

1. Crop rotation (*Kulima mwa kasinthasintha)*
2. Manure application (*Kuthira Manyowa)*
3. Early yielding variety (*Kubzala mbeu zocha msanga)*
4. Fertilizer application (*Kuthira fetereza)*
5. Legume crop residue mulch (*Kuphimbira ndi masangwi a mbeu zathu za mgulu la nyem*
6. Maize crop residue mulch *(Kuphimbira ndi mapesi a chimanga)*
7. Intercropping (*Kulima mwa kasakaniza) ba)*
8. Minimum tillage (*mtayakhasu)*
9. Deep tillage (*Kulima mozama/mokuya)*
10. Pre-emergence herbicide (*kuthira mankhwala okupha tchire [wothira mbeu zisanamere])*
11. Maize residue incorporation
12. Legume residue incorporation
13. Maize + legume residue mix incorporation
14. Tobacco pellet application
15. Maize bran application
16. Ash application
17. Planting leguminous trees (e.g., tephrosia)
99. Other (specify) (*Zina [tchulani])*

CODE AA

0. None/no change

(positive) Ubwino wake

1. Striga came back **less in short term** (same season) (*Kaufiti anemeranso koma wocheperapo m'chaka chomwecho)*
2. Striga came back **less in the long term** (next/multiple season/s) (*Kaufiti anameranso koma wocheperapo patapita nthawi [chaka/zaka] zotsatira)*
3. Striga did not come back at all that season (same season) (*Kaufiti sanamerenso m'chaka chimenecho)*
4. Soil fertility increased (*chonde chinaonjezereka mu nthaka)*
5. Increased biomass for fuel or fodder (*mapesi wochuluka omwe anagwira ntchito ngati nkhuni kapena chakudya cha ziweto)*
6. Maize yield **increased in the short term** (same season) (*zokolola chimanga zinachuluka m'chaka chomwecho)*
7. Maize yield **increased in the long term** (next season) (*Zokolola zinachuluka m'chaka chotsatira)*

(negative) kuipa kwake

12. Striga came back **more in short term** (same season) (*Kaufiti anameranso m'chaka chomwecho koma wochulukirapo)*
13. Striga came back **more in the long term** (next season) (*Kaufiti anameranso wochuluka m'chaka chotsatira)*
14. Maize yield **decreased in the short term;** harvested little (same season) (*Zokolora zinachepa m'chaka chimenecho)*
15. Maize yield **decreased in the long term;** harvested little (next season) (*zokolola chimanga zinachepa m'chaka chotsatira)*
16. Aggregate food production decreased (*Chakudya chonse tikachiphatikiza chinachepa)*
17. Pest incidence increased; harbored pests (*Tizilombo toononga mbeu tinachuluka)*
18 Profit (from on-farm production) decreased (*Phindu [purofiti] lochokera ku zokolola zathu linachepa)*
19. On-farm labor increased (*Ntchito yogwira pamundapo inachuluka)*

8. Aggregate food production increased *Chakudya (chonse tikachiphatikiza chinachuluka)* 9. Pest incidence reduced (*tizilombo toononga mbeu tinachepa)* 10. Profit (from on-farm production) increased *(Phindu [purofiti] lochokera ku zokolola zathu linachuluka)* 11. On-farm labor decreased (*Ntchito yogwira pamundapo inachepa)*	20. Inputs became unavailable (*zipangizo zogwilira ntchito ya ulimi zinasowa)* 21. Inputs became too expensive (*zipangizo zogwilira ntchito ya ulimi zinakwera mtengo)* 22. Delayed Striga emergence 23. Reduced overall weed pressure 24. Improved water retention/soil moisture holding capacity 25. Reduced erosion/Improved soil structure/texture 26. Sustained Striga emergence; prevented Striga problem from getting worse 27. Damaged soil 99. Other (specify) (*Zina [tchulani])*
CODE BB 0. The same season *M'chaka chomwecho* 1. The following season (*Chaka chotsatira)* 2. The following 2 seasons (*Patadutsa zaka ziwiri)*	3. The following 3-5 seasons (*Patatha zaka za pakati pa zitatu mpaka zisanu)* 4. The following 6-10 seasons (*Patatha zaka za pakati pa chisanu n'chimodzi mpaka zaka khumi)* 5. The following 10+ seasons (*Patatha zaka zoposera khumi)*

CODE CC	CODE DD
0. None/nobody 1. Neighbor/Farmer (*Wokhala moyandikana naye/mlimi)* 2. Farmer group/coop (*ku gulu/bungwe la alimi)* specify) (*Zina [tchulani])* 3. NGO/Inter. Org. (*Mabungwe wosakhala a boma)* 4. Agro-dealer (*Wogulitsa zipangizo za ulimi)* 5. Family, relatives 99. Other (specify) (*Zina [tchulani])*	0. None (*Palibe)* 1. 0-5 2. 5-10 3. 10-15 4. 15-20 5. +20

CODE EE	CODE FF	CODE GG	CODE HH	CODE II
1. Common bean (*Nyemba)* 2. Soybean (*Soya)* 3. Cowpea *Khobwe* 4. Groundnut (peanut) (*Mtedza)* 5. Pigeon Pea (*Nandolo)* 6. Cereal (sorghum, millet) (*mawere, mapira)* 7. Cash Crop (Tobacco, Cotton) (*Fodya, Thonje)* 8. Root tuber/starch (Cassava, Pumpkin, Sweet Potato, Irish Potato) (*Chinangwa, mawungu, mbatata, mbatata ya kachewere)* 99. Other (specify) (*Zina [tchulani])*	1. Saved seed (*Mbeu yosungidwa)* 2. Purchased (*Mbeu yochita kugula)* 3. Subsidy *(Mbeu yotsika mtengo)* 4. Private trader (*Mbeu yogula kwa a ma bizinesi)* 5. NGO (free) (*Kuchoka ku mabungwe osakhala a boma [yaulere])* 99. Other (specify) (*Zina [tchulani])*	1. Cow *(Ng'ombe)* 2. Goat (*Mbuzi)* 3. Chicken or other poultry (*Nkhuku kapena zina za gulu la nkhuku)* 4. Pig (*Nkhumba)* 5. Compost mixed with manure (*Manyowa)* 6. NPK (*Fetereza wa chitowe)* 7. Urea (*Fetereza wa Urea)* 8. CAN (*Fetereza wa CAN)* 9. Maize residues 10. Legume residues 11. Maize + legume residue mix 12. Maize bran 99. Other (specify) (*Zina [tchulani])*	1. From own production/livestock (*Kuchokera ku ziweto zathu)* 2. Purchased (*Kugula)* 3. Paid ganyu to collect/apply (*Ndinalemba waganyu kuti akatenge/athire)* 4. Given by other farmer (*Ndinapatsidwa ndi mzanga)* 5. Gathered in village (*Ndinasonkhanitsa a mmudzi)* 6. Subsidy (*Ndinapeza wotsika mtengo)* 7. Received from NGO (*Ndinalandira kuchokera ku mabungwe omwe si aboma)* 8. Agro-dealer (*Wogulitsa zipangizo za ulimi)* 9. Family, relatives 99. Other (specify) (*Zina [tchulani])*	1. When turning ridges early right after harvest (*Popanga mizere moyambilira tikangomaliza kukolora)* 2. When turning ridges just before first planting rains (*Popanga mizere mvula ikayandikira)* 3. When turning ridges after first planting rains (*Popanga mizere mvula yoyamba ikangogwa)* 4. After ridge turning but before planting (incorporate) (*Mizere itapangidwa koma tisanadzale)* 5. After ridge turning but before planting (planting station application) (*Kuthira pa phando [tisanadzale])* 6. At planting station with seed *Kuthira pa phando (nthawi yodzala)* 7. About 10 days after planting with first weeding (*Patadutsa masiku khumi chidzalireni m'nthawi ya kupalira koyamba)* 8. About 30 days after planting with second weeding (*Patadutsa masiku makumi atatu chidzalireni m'nthawi ya kupalira kachiwiri)* 9. Dig basin/zaii pit 99. Other (specify) (*Zina [tchulani])*

CODE JJ	CODE KK	CODE LL	CODE MM
1. Crop rotation (*Kulima mwa kasinthasintha)* 2. Manure application (*Kuthira Manyowa)* 3. Early yielding variety (*Kubzala mbeu zocha msanga)* 4. Fertilizer application (*Kuthira fetereza)*	1. Cow *(Ng'ombe)* 2. Goat (*Mbuzi)* 3. Chicken or other poultry (*Nkhuku kapena zina za gulu la nkhuku)* 4. Pig (*Nkhumba)* 5. Compost mixed with manure (*Manyowa)* 6. NPK (*Fetereza wa*	1. Common bean (*Nyemba)* 2. Soybean (*Soya)* 3. Cowpea (*Khobwe)* 4. Groundnut (peanut) (*Mtedza)* 5. Pigeon Pea (*Nandolo)* 6. Cereal (sorghum, millet) (*mawere, mapira)*	1. No time *Analibe mpata (nthawi)* 2. Shortage of household labor (*Kuchepa kwa wogwira ntchito panyumba)* 3. Could not hire outside labor (*Sakanakwanitsa kulemba a ganyu)* 4. Illness/death in family (*Matenda/Maliro wokhudza banja)* 5. Rain (*Mvula)*

5. Legume crop residue mulch (*Kuphimbira ndi masangwi a mbeu zathu za mgulu la nyemba)* 6. Maize crop residue mulch *(Kuphimbira ndi mapesi a chimanga)* 7. Intercropping (*Kulima mwa kasakaniza)* 8. Minimum tillage (*mtayakhasu)* 9. Deep tillage (*Kulima mozama/mokuya)* 10. Pre-emergence herbicide (*kuthira mankhwala okupha tchire [wothira mbeu zisanamere])* 11. Maize residue Incorporation 12. Legume residue Incorporation 13. Maize + legume residue mix 14. Maize bran Application 15. Leguminous trees (e.g., tephrosia) 99. Other (specify) (*Zina [tchulani])*	*chitowe)* 7. Urea (*Fetereza wa Urea)* 8. CAN (*Fetereza wa CAN)* 9. Maize Bran 99. Other (specify) (*Zina [tchulani])*	7. Cash Crop (Tobacco, Cotton) (*Fodya, Thonje)* 8. Root tuber/starch (Cassava, Pumpkin, Sweet Potato, Irish Potato) (*Chinangwa, mawungu, mbatata, mbatata ya kachewere)* 99. Other (specify) (*Zina [tchulani])*	6. Market price for outputs (e.g., legume grain) was too low (*Mitengo ya zokolola (mwachitsanzo, mbeu za gulu la nyemba) inali yotsika kwambiri)* 7. Ganyu labor took away from practice (*Aganyu anatsata njira ina osakhala imene anauzidwa)* 8. Could not afford inputs (*Sindikadakwanitsa kupeza zipangizo zotsatilira njirayi)* 9. Input availability (*Kapezekedwe ka zipangizo)* 10. Did not know; Not enough information/training (*samadziwa za mmene ndingatsatire njirayi; sanaphunzitsidwe/sanapatsidwe upangiri)* 99. Other (specify) (*Zina [tchulani])*

CODE NN

1. Poor
2. Fair
3. Good
4. Very Good
5. Excellent

Variable	*Description of Variables*	*Input (e.g., equation, model function)*
Abandonment Rate	Percent of readopters that abandon intercropping across their two maize fields	(Parasitism of Farmer Field via Seed Dispersal/2)*Percent Abandon After Sec Neg Outcome
Abandoners	Population of readopters that have abandoned the practice after a second negative outcome	Abandonment-Rejoin Potential Adopters
Abandonment	Flow of readopters that have abandoned intercropping	((Disadoption Rate+Abandonment Rate)/2)*Striga Control Practice Readopters
Additional Ha	Flow of new land area cultivated for maize production	(0.85*Pop Growth)*Avg Maize Area per HH
Adoption	Flow of potential adopters that have taken up intercropping	(0.85*Pop Growth)*Avg Maize Area per HH
Adoption Rate	Percent of potential adopters that cultivate intercropping systems across two maize fields	((Adoption Rate via Advert+"Adoption Rate via Ag- Ext")/2) + ((Adoption Rate via Obs+Adoption Rate via Word of Mouth)/2)
Adoption Rate via Advert	Percent of potential adopters that cultivate an intercropping system across two maize fields after receiving an advertisement and/or hear about it via radio	IF THEN ELSE(Yield Percent Difference<-0.2,(0.09*Prob of Receiving Advert)*Percent Satisfied with Maize Yield,0.09*Prob of Receiving Advert)
Adoption Rate via Obs	Percent of potential adopters that cultivate an intercropping system across two maize fields after seeing one field being cultivated in their locality	Net Prob of Observing a SCP with Pos Result*0.37
Adoption Rate via Word of Mouth	Percent of potential adopters that cultivate an intercropping system across two maize fields after hearing about its benefits from a fellow smallholder	Net Prob of Rec Pos Info via Word of Mouth*0.97
Aggregate Control Rate	Striga emergence rate within an intercropping system with (or without) fertilizer application	IF THEN ELSE(Fertilizer Application=1,(0.2+Prob of Emergence WITH SCP),Prob of Emergence WITH SCP)
Avg Sole Maize Yield	Maize yield per Ha across the Central Region from 1996-2016	Lookup Function: [(0,0)-(20,2300)]
Climate	Rainfall from 1996-2016. The average rate was 1421mm with a SD of 356mm	Lookup Function: [(0,0)-(20,1)]
Cost Decrease via More Fields with Legumes	Percent of smallholders express that seed became to expensive to continue intercropping	Lookup Cost Decrease via More Fields with Legumes(Fields WITH SCPs)
Disadopt because No Longer Needed	Striga emergence is lowered and household feels they no longer need to cultivate the intercrop	0.09*((Striga Emergence Decreases/2)/Striga Control Practice Adopters)*Cost Decrease via More Fields with Legumes
Disadoption Rate because Inadequate Striga Control	Striga emergence either continues or does not decrease fast enough; thus, intercropping is halted	0.1392*Prob of Emergence WITH SCP
Disadoption Rate from Reduced Maize Yield	Intercropping is viewed as a reason for lost maize yield and is halted	Percent NOT Satisfied with Maize Yield

Disadoption	Flow of adopters that have halted intercropping	Striga Control Practice Adopters*Disadoption Rate
Disadoption Rate	Percent of adopters that stop cultivating intercropping systems across two maize fields	(Disadopt because No Longer Needed+Disadoption Rate because Inadequate Striga Control+Disadoption Rate from Reduced Maize Yield)/3
Fertilizer Application	Basal fertilizer application (split applied: 33 kg NPK/ha at sowing; 23:21:0 + 4S formula; top dress Urea [46%N] or Calcium Ammonium Nitrate [28%N] 21 days after sowing)	0 or 1 (Depending on Scenario)
Fields In Process fo Eradication	Population of fields intercropped and Striga emergence is decreasing across consecutive seasons	Striga Emergence Decreases-Zero Striga Emergence
Fields where Practices were Added	Flow of maize fields that were recently intercropped with legumes	(Adoption+Readoption)*2
Fields where Practices were Dropped	Flow of maize fields where intercropping was recently halted	(Abandonment+Disadoption)*2
Fields where Striga Emerged	Population of fields where Striga recently emerged or spread persists	Striga Emergence Increases-Striga Emergence Decreases
Field where Striga Seed Spread	Population of fields where Striga seed landed and is awaiting germination	Seed Transfer-Striga Emergence Increases
Fields with Flowers to Spread Seed	Population of fields where Striga was able to mature, flower and spread seed	Fields where Striga Emerged+Fields In Process of Eradication
Fields WITH SCPs	Population of fields where an intercropping systems is being cultivated	Fields where Practices were Added-Fields where Practices were Dropped
FINAL TIME	Function specified by Vensim®	No value specified
General Populous	Flow of new households that are cultivating maize fields	IF THEN ELSE(Maize Field Expansion=0,Pop Growth*0,(Pop Growth*0.85))
Growth Rate	Percent of population growth per year	Lookup Function: [(0,0.25683)-(20,0.42913)]
INITIAL TIME	Function specified by Vensim®	No value specified
Kg Gain	Percent maize yield gain per Ha due to climatic events, intercropping and/or fertilizer application	IF THEN ELSE(Fertilizer Application=1,0.42*Sole Maize Yield,0.18*Sole Maize Yield)
Kg Loss	Percent maize yield loss per Ha due to climatic events, intercropping and/or fertilizer application	IF THEN ELSE(Fertilizer Application=1,0.283*Sole Maize Yield,0.473*Sole Maize Yield)
Lookup Cost Decrease via More Fields with Legumes	Percent of households that express that seed is too expensive which corresponds to the number of adopters that are contributing seed to the market	Lookup Function: [(0,0)-(20,1)
Lookup Maize Yield Satisfaction	Percent of adopters that are satisfied based on maize yield in an intercropping system relative to maize yield in a monoculture	Lookup Function: [(-1,0)-(0.9,1)]

Lookup Parasitism of Farmer Fields via Seed Dispersal	Probability of farmer fields where seed will be transferred relative to the number of fields that have mature Striga	Lookup Function: [(0,0)-(30,1)]
Lookup Prob of Seeing SCP	Probability of seeing a field with an intercropping field relative to the population of adopters	Lookup Function: [(0,-0.3)-(20,1)]
Maize Field Expansion	Flow of new fields that are being cultivated with maize based on population growth	IF THEN ELSE(Total Maize Fields>(Maximum Fields Available in Central Region),0, (Additional Ha/Avg Ha per Maize Field))
Maize Ha Added	Population of new maize fields cultivated in the Central Region	Additional Ha
Maize Kg per Ha WITH SCP	Maize yield received when cultivating an intercropping system	IF THEN ELSE(Optimal Conditions=1,Sole Maize Yield+Kg Gain, Sole Maize Yield-Kg Loss)
Net Prob of Observing a SCP with Pos Result	Probability of seeing a field with an intercropping field that has a positive result relative to those with negative results	IF THEN ELSE(Prob of Seeing a SCP with Pos Result-Prob of Seeing a SCP with Neg Result<0,0,Prob of Seeing a SCP with Pos Result -Prob of Seeing a SCP with Neg Result)
Net Prob of Rec Pos Info via word of Mouth	Probability of hearing about the benefits of intercropping relative to setbacks	IF THEN ELSE(Prob of Rec Pos Info via Word of Mouth - Prob of Rec Neg Info via Word of Mouth < 0, 0, Prob of Rec Pos Info via Word of Mouth - Prob of Rec Neg Info via Word of Mouth)
Num of Fields with Neg Result	Population fields with an intercropping system where a negative result occurred	(SCP Adopters Received Neg Outcome)*2
Num of Fields with Pos Result	Population fields with an intercropping system where a positive result occurred	((SCP Adopters Received Pos Outcome*2)+Zero Striga Emergence)
Optimal Conditions	If rainfall during the growing seasons below 1065mm,	Climate(Year)
Parasitism of Farmer Field via Seed Dispersal	Percent of fields parasitized based on the surrounding population of fields with mature Striga	Lookup Parasitism of Farmer Fields via Seed Dispersal(Fields with Flowers to Spread Seed)
Percent NOT Satisfied with Maize Yield	Percent of adopters that are not satisfied with the maize yield they received from an intercropping system relative to the maize yield in a monoculture	(1-Percent Satisfied with Maize Yield)
Percent Receive Neg Outcome Beyond Maize Loss	Percent of adopters that receive a negative outcome such as increased labor, increase Striga emergence, etc.	Prob of Emergence WITH SCP
Percent Satisfied with Maize Yield	Percent of adopters that are satisfied with the maize yield they received from an intercropping system relative to the maize yield in a monoculture	Lookup Maize Yield Satisfaction(Yield Percent Difference)
Pop Growth	Annual addition of Malawians to the Central Region's population	Growth Rate(Year)

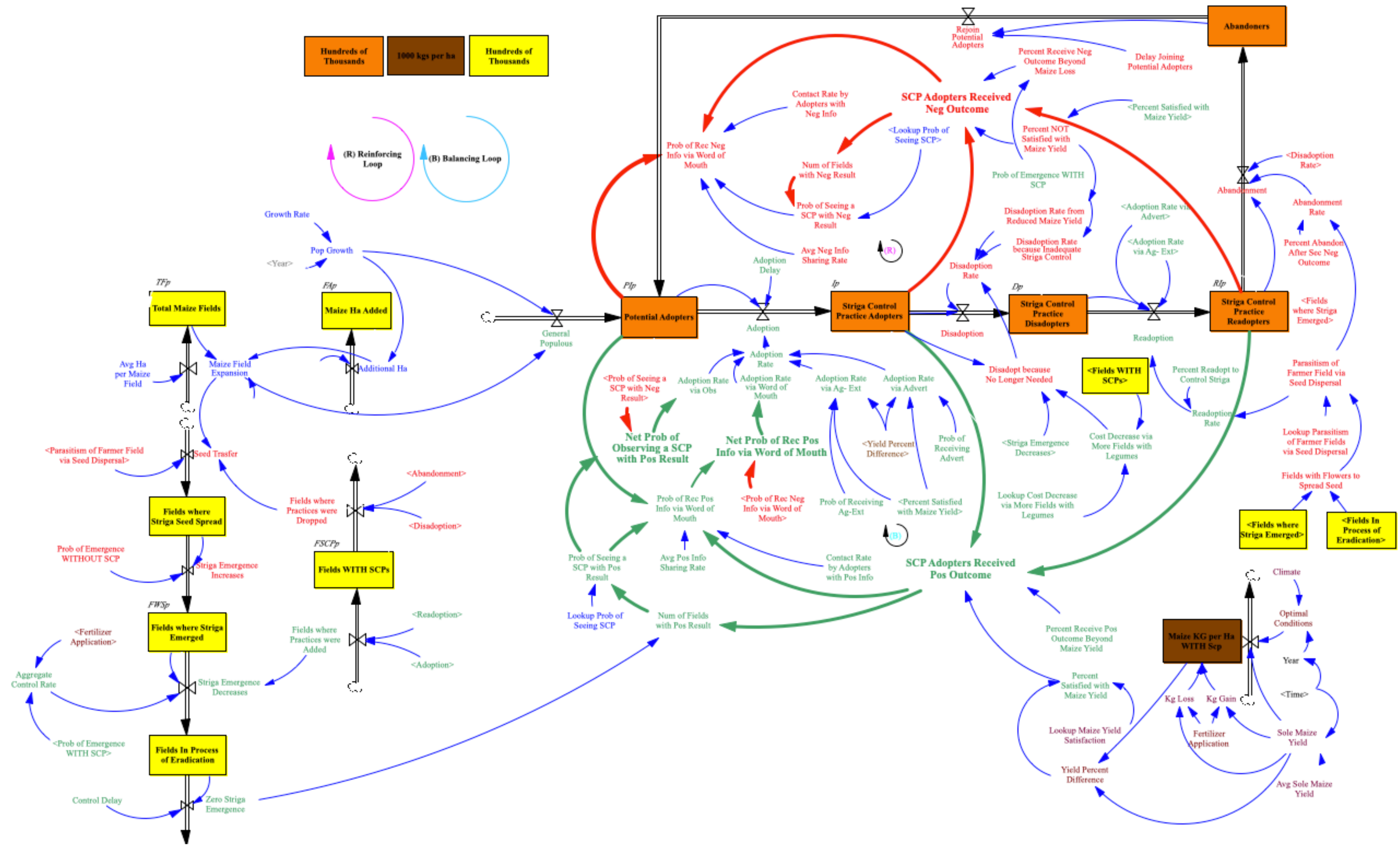
Potential Adopters	The population of households that are cultivating a monoculture, but may adopt intercropping	(General Populous+Rejoin Potential Adopters-Adoption)+Rejoin Potential Adopters
Prob of Emergence WITHOUT SCP	Probability of Striga emerging in monoculture after seed lands or is laying dormant in a field	Prob of Emergence WITHOUT SCP
Prob of Rec Neg Info via Word of Mouth	Probability a potential adopter hears about a negative aspect of intercropping from an adopter and/or another potential adopter that saw a field with a negative outcome	(((Contact Rate by Adopters with Neg Info*SCP Adopters Received Neg Outcome)+(Potential Adopters*Prob of Seeing a SCP with Neg Result))*Avg Neg Info Sharing Rate)/Potential Adopters
Prob of Rec Pos Info via Word of Mouth	Probability a potential adopter hears about a positve aspect of intercropping from an adopter and/or another potential adopter that saw a field with a positive outcome	(((Contact Rate by Adopters with Pos Info*SCP Adopters Received Pos Outcome)+(Potential Adopters*Prob of Seeing a SCP with Pos Result))*Avg Pos Info Sharing Rate)/Potential Adopters
Prob of Seeing a SCP with Neg Result	Probability a potential adopter sees a negative outcome in an adopter's field	Lookup Prob of Seeing SCP(Num of Fields with Neg Result)
Prob of Seeing a SCP with Pos Result	Probability a potential adopter sees a positive outcome in an adopter's field	Lookup Prob of Seeing SCP(Num of Fields with Pos Result)
Readoption	Flow of disadopters that have taken up intercropping again	((Readoption Rate+"Adoption Rate via Ag- Ext"+Adoption Rate via Advert)/3)*Striga Control Practice Disadopters
Rejoin Potential Adopters	Flow of abandoners that are open to potentially cultivating an intercropping system again	Abandoners/Delay Joining Potential Adopters
Readoption Rate	Percent of disadopter that cultivate an intercropping system again	Parasitism of Farmer Field via Seed Dispersal*Percent Readopt to Control Striga
SAVEPER	Function specified by Vensim®	No value specified
SCP Adopters Received Neg Outcome	Population of adopters that received a negative outcome such as maize yield loss, increased labor, increase Striga emergence, etc.	((Striga Control Practice Readopters+Striga Control Practice Adopters)*Percent NOT Satisfied with Maize Yield)+ (Striga Control Practice Readopters+Striga Control Practice Adopters)*Percent Receive Neg Outcome Beyond Maize Loss
SCP Adopters Received Pos Outcome	Population of adopters that received a positive outcome such as maize yield increase, lower weed prevalence, increased soil fertility, alternative income, etc.	((Striga Control Practice Adopters+Striga Control Practice Readopters)*Percent Receive Pos Outcome Beyond Maize Yield)+ ((Striga Control Practice Adopters+Striga Control Practice Readopters)*Percent Satisfied with Maize Yield)
Seed Transfer	Flow of fields where Striga just landed	(Fields where Practices were Dropped+Maize Field Expansion)*Parasitism of Farmer Field via Seed Dispersal
Sole Maize Yield	Maize yield received when cultivating a monoculture	Avg Sole Maize Yield Across Dedza(Time)

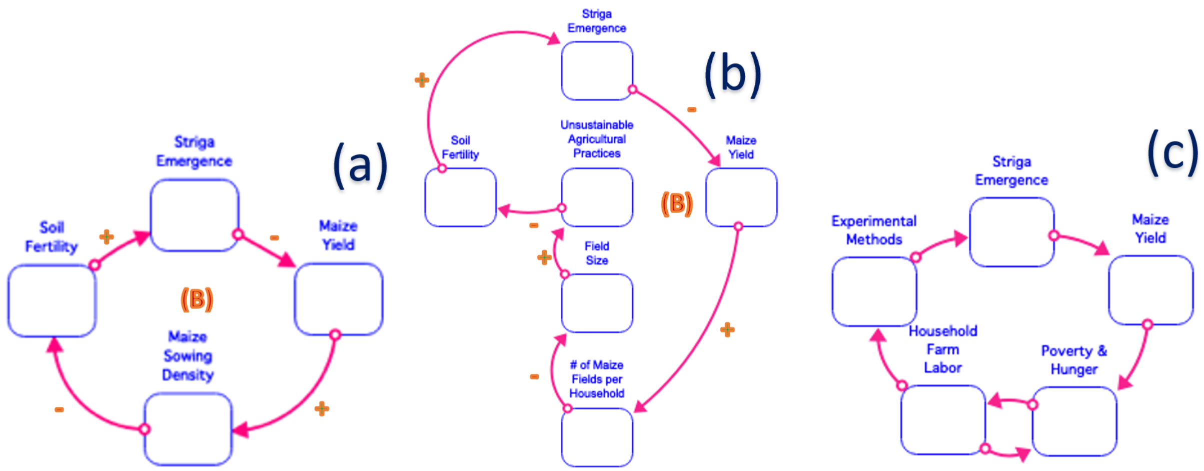
Striga Control Practice Disadopters	Population of households that once intercropped, but halted the practice	Striga Control Practice Disadopters= INTEG (Disadoption-Readoption, Dp)
Striga Emergence Decreases	Flow of fields where Striga emergence is decreasing due to the cultivating of an intercrop and/or fertilizer application	IF THEN ELSE((Aggregate Control Rate*Fields where Practices were Added)>Fields where Striga Emerged,0, (Aggregate Control Rate*Fields where Practices were Added))
Striga Emergence Increases	Flow of fields where Striga emergence is increasing due surrounding fields with Striga and no control practices put in place to decrease seed spread and/or spread	(Fields where Striga Seed Spread*Prob of Emergence WITHOUT SCP)
Time	Function specified by Vensim®	No value specified
TIME STEP	Function specified by Vensim®	No value specified
Total Maize Fields	Population of fields in the Central Region cultivated with maize	Maize Field Expansion
Year	1996 through 2016	MODULO(Time,20)
Yield Percent Difference	The difference in kilograms between a maize yield received from a intercropping field and a monoculture	(Maize KG per Ha WITH Scp-Sole Maize Yield)/Sole Maize Yield

Note- All variable labels are written as they are presented in the more detailed model located in Appendix 5. Input equations and model functions were written in a form that can be entered in Vensim®.

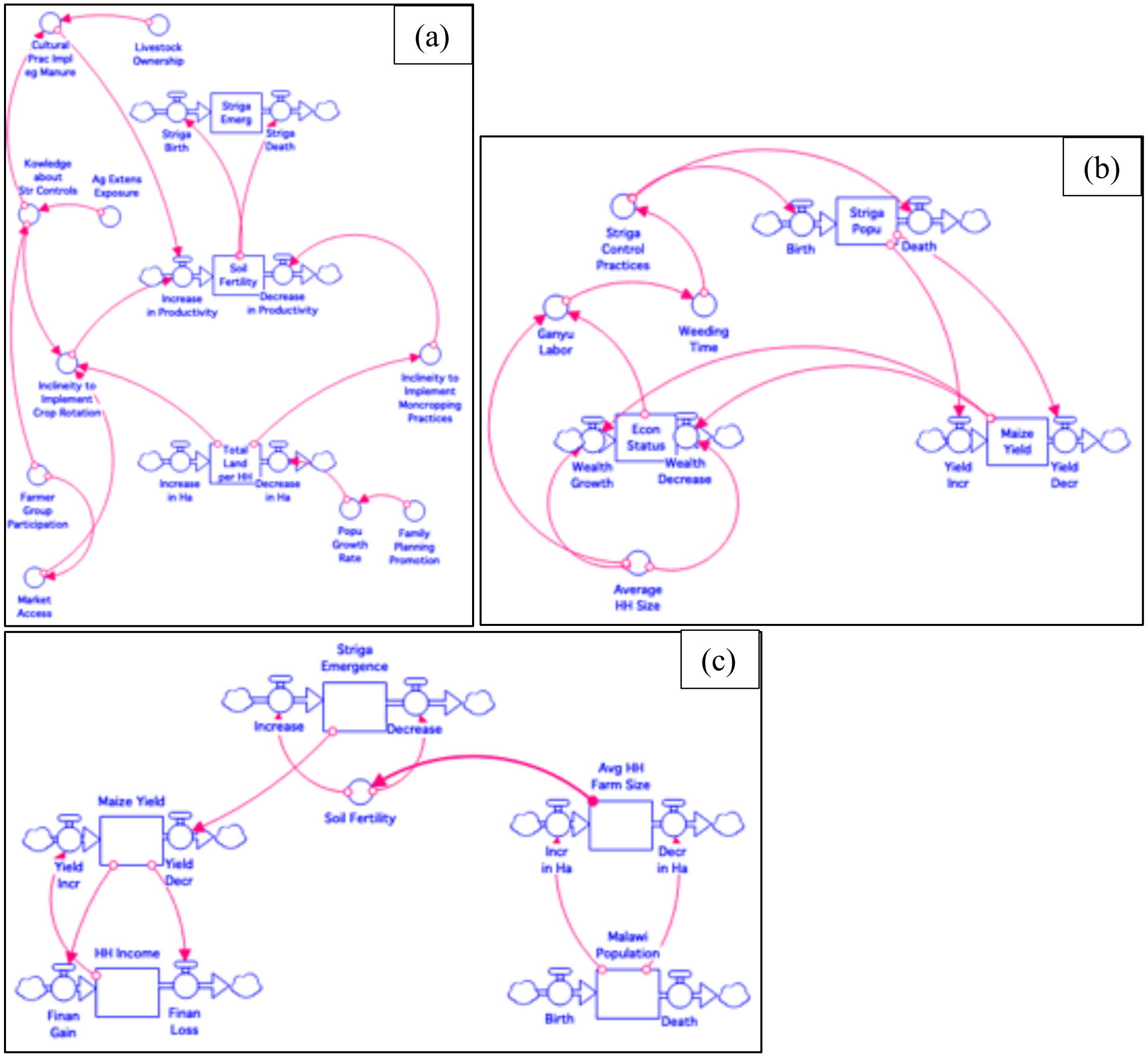
Variable	*Description of Variables*	*Input (e.g., value)*
Adoption Delay	Number of years until potential adopter takes before cultivating an intercropping system across two maize fields after hearing, seeing and/or experimenting with the practice	2
Adoption Rate via Ag-Ext	Percent of potential adopters that cultivate an intercropping system across two maize fields after receiving a visit from an agricultural extension development officer	.69
Avg Ha per Maize Field	Average size of single maize field among smallholder households residing in the Central Region	0.417
Avg Maize Area per HH	Average size of two maize fields cultivated by smallholder household	0.834
Avg Neg Info Sharing Rate	Number of individuals a smallholder shares negative aspects about intercropping technology in terms of controlling striga	0.013
Avg Pos Info Sharing Rate	Number of individuals a smallholder shares positive aspects about intercropping technology in terms of controlling striga	0.07
Contact Rate by Adopters with Neg Info	Percent of potential adopters current adopters will share their negative experiences with regarding intercropping	0.2
Contact Rate by Adopters with Pos Info	Percent of potential adopters current adopters will share their positive experiences with regarding intercropping	0.46
Control Delay	Number of consecutive seasons required to cultivate intercropping until striga emergence no longer persisted	5
Delay Joining Potential Adopters	Years before rejoining the potential adopter population	5
Dp	Starting population of disadopters	1.5557
FAp	Starting area cultivated with maize as of 2016	8.23838
FSCPp	Starting population of fields where an intercropping systems is being cultivated	12.8416
FWSp	Starting population of fields with emerging Striga	11.4587
Ip	Initial Striga Control Practice Adopter population	6.4208
Percent Abandon After Sec Neg Outcome	Percent of readopters that receive a negative result while intercropping	0.2
Perc Readopt to Control Striga	Percent where Striga emerged and opted to cultivate an intercropping system again to control the weed	0.12
Percent Receive Pos Outcome Beyond Maize Yield	Percent of adopters that receive a positive outcome such as lower weed prevalence, increased soil fertility, alternative income, etc.	0.65
PIp	Starting population of potential adopters	9.87815

Prob of Emergence WITH SCP	Probability of Striga emerging in an intercropping system after seed lands or is laying dormant in a field	0.35
Prob of Receiving Advert	Probability of a potential adopter learning about intercropping from radio, pamphlet and/or other form of advertising	0.16
Prob of Receiving Ag-Ext	Probability of a potential adopter learning about intercropping from an agricultural extension development officer	0.69
RIp	Initial Readopter population	0.1387
Striga Control Practice Adopters	Population of households that intercrop two maize fields with legumes	1.5557
Striga Control Practice Readopters	Population of households that once halted the practice, but have begun cultivating two maize fields with an intercrop	0.1387
TFp	Initial number of maize fields cultivated in the Central Region	19.7563





Note – (B) indicates a balancing loop while “-” and “+” indicate negative and positive effects on the variables population (respectively).



Note: All models were drawn and presented at the workshop and later created in systems modeling software named Vensim®

Step 1

Step 2

Step 3