Journal of Agriculture and Food Research 16 (2024) 101099

Contents lists available at ScienceDirect

Journal of Agriculture and Food Research

journal homepage: www.sciencedirect.com/journal/journal-of-agriculture-and-food-research

Understanding spillover effects of sustained adoption of sustainable agricultural practices on household resilience to food shocks: Evidence from Malawi's sustainable food systems program

Wisdom Richard Mgomezulu [a,b,c,*], Abdi-Khalil Edriss [a], Kennedy Machira [a], Innocent Pangapanga-Phiri [d], Moses Chitete [e], Mwayi Mambosasa [a], George Chidimbah Munthali [e], Frank Mnthambala [e]

[a] Lilongwe University of Agriculture and Natural Resources, Department of Agricultural Economics, P.O. Box 219, Lilongwe, Malawi
[b] Malawi University of Business and Applied Sciences, Faculty of Commerce, P/Bag 303, Blantyre 3, Malawi
[c] Avant-Garde Consultants Limited, P.O. Box 31599, Lilongwe, Malawi
[d] Lilongwe University of Agriculture and Natural Resources, Department of Environmental Sciences, P.O. Box 219, Lilongwe, Malawi
[e] University of Livingstonia, P.O. Box 112, Mzuzu, Malawi

A R T I C L E I N F O

Keywords:
Sustained adoption
Spillover effects
Sustainable agricultural practices
Resilience
Recursive bivariate probit

A B S T R A C T

Food insecurity is one of the challenges the world has to do away with by 2030. However, to achieve a hunger-free world, the efficient use of allocated resources remains critical at both household and institutional level. The investments in climate-resilient and sustainable agricultural practices should cascade beyond the target farmers whereby longevity and sustainability of the interventions is embedded in the informal community networks as a spill-over effect to the non-targeted farming households. The paper analyzed the spillover effects of the climate-resilient program in Malawi and its effects on household resilience to food shocks among the participants and non-participants of the Sustainable Food Systems in Malawi (FoodMa) project. The main research questions were: (i) Are there any Direct and Spillover Effects of FoodMa on Sustained Adoption? And (ii) Is there any Spillover Effect of Sustained Adoption of SAPs on Resilience to Food Shocks? Analytically, the study used recursive bivariate probit (RBP) models and a two-stage predictor substitution model with instrumental variables to assess the effect of sustained adoption of sustainable agricultural practices (SAPs) on household resilience to food shocks. The results showed that there was an increased probability of sustained adoption of mulching, organic farming, and pit planting by 45%, 66%, and 25%, respectively, by the project participants. On the other hand, the project has a strong spillover effect on promoting sustained mulching of non-project participants by 57%. Furthermore, the study found that sustained adoption of mulching by project non-participants significantly reduces the food insecurity levels of households by improving their resilience to food shocks. The sustainable adoption of SAPs has the potential to reduce food insecurity for both project participants and non-participants. However, the use of field demonstrations and training should be emphasized because they boost adoption probability and spillover effects.

1. Introduction

Malawi, a small country located in southeastern Africa, is facing a serious issue - hunger. According to the Global Hunger Index (GHI), Malawi ranks 87th out of 121 countries, with a GHI of 20.7 in 2022. Studies show that a staggering 18% of the population is undernourished, and 35% of children under five are stunted [1]. These alarming statistics highlight the urgent need for improving the food security status of the Malawian population. Although agriculture has always been the backbone of Malawi's economy, heavy reliance on rain-fed agriculture in smallholder farms has made the country vulnerable to the effects of climate change. In recent years, increasing droughts, high temperatures, and uneven rainfall patterns have significantly decreased maize yields by 20% per year. Experts predict that this trend will continue, with a potential decrease of more than 50% in maize yields due to nitrogen stress.

* Corresponding author. Lilongwe University of Agriculture and Natural Resources, Department of Agricultural Economics, P.O. Box 219, Lilongwe, Malawi.
E-mail address: wmgomezulu@poly.ac.mw (W.R. Mgomezulu).

https://doi.org/10.1016/j.jafr.2024.101099
Received 29 June 2023; Received in revised form 7 March 2024; Accepted 9 March 2024
Available online 21 March 2024

Nitrogen is a crucial nutrient for plant growth, but in most soils, its concentration is below what is needed for optimal crop yields. In Malawi, where the soils are already poor, farmers rely on adding nitrogen fertilizers to achieve better yields. However, poverty, the rising cost of inorganic fertilizers, and even global events such as the ongoing war in Ukraine have made it challenging for farmers to access these essential fertilizers. It is therefore evident that Malawi's food security is at risk, and urgent action needs to be taken. Initiatives such as improving soil fertility, promoting sustainable farming practices, and providing support to smallholder farmers can help alleviate the effects of climate change and poverty on Malawi's agricultural sector. With these efforts, we can work towards a future where Malawi's population is well-nourished and food secure.

The impact of climate change is being felt across the globe, but one region in particular is bearing the brunt of its devastating effects - Sub-Saharan Africa (SSA). According to the Intergovernmental Panel on Climate Change (IPCC), SSA is facing the highest levels of exposure and the lowest adaptive capacity, making it the most vulnerable region to climate change [2]. In the past two decades alone (2000–2010 and 2011–2020), temperatures in SSA have risen by an alarming average of 0.45 and 0.55 °C, respectively. This rise in temperature has led to more frequent droughts and erratic rainfall patterns, exacerbating the already dire situation in the region [3].

The consequences of these climate-related challenges are far-reaching, particularly when it comes to food security. The state of soil fertility in SSA is deteriorating rapidly, compounding the already dire situation. According to a report by GoM [4], a staggering 5.4 million people in Malawi - both in rural and semi-urban areas - are currently classified as severely chronically food insecure. On top of that, an additional 4.4 million Malawians are facing mild food insecurity, painting a grim picture of the situation in the country.

The Malawi Vulnerability Assessment Committee (MVAC) echoed these findings in their 2020 report, highlighting the daunting challenge of building resilience to food insecurity in the country. MVAC [5] reported a staggering increase in the number of vulnerable food insecure people from 640,009 in 2014 to a staggering 2.6 million in 2020. This alarming rise can be attributed to the increasing frequency of droughts and erratic rainfall patterns, which have left millions of people struggling to feed themselves and their families.

Efforts towards sustainable production systems have taken center stage in recent years. The Malawi National Agriculture Policy (NAP) has identified sustainable agricultural production and productivity as a top priority, prompting a shift in development efforts. In fact, the Farm Input Subsidy Program (FISP) was revamped in 2021 to the Affordable Input Program (AIP) with the goal of reaching 4,279,100 smallholder farmers. This move has come at a cost, with the program's budget doubling to a hefty K160 billion (equivalent to US$1 = K800). However, concerns have been raised by various stakeholders about the sustainability of this program, given its high cost. It currently consumes a staggering 74 percent of the agricultural budget and 16 percent of the overall Malawian budget (AGRA, 2017). Clearly, there is a pressing need for more cost-effective and sustainable solutions to enhance farmers' resilience to food shocks, in line with the NAP's vision.

Scholars have been advocating for the adoption of sustainable agricultural practices (SAPs) as a response to the challenges posed by climate change. These practices, such as soil fertility management (SFM) and climate-smart agriculture (CSA), including conservation agriculture (CA), have gained recognition from researchers (Ogada et al., 2020; Ouedraoyo et al., 2019; Bedeke et al., 2019; Ogunniyi et al., 2018; Mgomezulu et al., 2018). SAPs refer to a range of techniques aimed at enhancing farmers' ability to adapt to climate change while also increasing productivity and sustainability of natural resources [6]. In countries like Malawi, where CA and integrated soil fertility management (ISFM) are widely practiced, the benefits have been significant. These include improved soil organic matter, water retention, soil biology, and crop yield (Ngwira et al., 2012; Ngwira et al., 2013; Nyagumbo et al., 2016; Steward et al., 2019; TerAvest et al., 2019). The use of CA has also led to positive outcomes, such as increased soil organic carbon, water infiltration, soil aggregate stability, and below-ground fauna (Mloza-Banda, Makwiza, & Mloza-Banda, 2016). Similarly, the application of ISFM, specifically the legume-legume intercrop (double-up legume) followed by maize with a reduced dose of inorganic nitrogen or compost, has resulted in higher maize yields compared to plots without legumes (Kalasa et al., 2018; Njira et al., 2012, 2013).

Despite the growing support for SAPs among scholars, the true scalability of these interventions remains a mystery. While SAPs are designed to efficiently reach a larger number of smallholder farmers compared to costly subsidy programs, the evidence is lacking. In order to truly understand the effectiveness and scalability of SAPs, it is crucial to explore their spillover effects. This not only sheds light on their effectiveness compared to traditional subsidies, but also highlights their potential for widespread implementation.

However, the ongoing debate surrounding SAPs has hindered the availability of conclusive evidence. While some studies, such as those by Pangapanga-Phiri and Mungatana [7], Mujeyi and Mudhara [8], and Ekman [9], have found them to be highly effective in improving yields, income, and food security for smallholder farmers, others, like Adimassu et al. [10] and McCarthy et al. [11], have reported conflicting results. Adimassu et al. [10] have observed a significant reduction in yields, while McCarthy et al. [11] have found no significant impact on the welfare of smallholder farmers. These discrepancies further highlight the need for a deeper understanding of the scalability of SAPs.

By delving into the spillover effects of SAPs, we can unlock their true potential and pave the way for a more sustainable and successful future for smallholder farmers. Let's strive for a revolution in smallholder farming through evidence-based decision making.

In this study, we examine the Sustainable Food Systems in Malawi (FoodMa) project, a case study that aimed at promoting the sustainable adoption of climate-resilient practices in areas of Malawi affected by climatic variability. The project focused on training farmers in various sustainable agricultural practices (SAPs), such as no tillage, mulching, and pit planting, with the ultimate goal of improving the resilience of smallholder farmers and achieving food security for all. Our goal was to not only analyze the direct effects of the interventions on SAP adoption, but also the indirect effects (spillover) and their impact on household resilience to food shocks. Taking inspiration from previous studies, we assessed the sustained adoption of SAPs rather than one-time adoption, as inconsistencies and high dis-adoption rates among farmers have hindered the conclusive evaluation of their effectiveness [12]. Furthermore, we followed the trend of assessing agricultural interventions at least two years after their implementation to truly gauge their sustainability [13–16].

As our planet faces the ever-growing threat of climate change, it is crucial to strengthen the resilience and sustainability of our food systems. Thankfully, there is hope in the form of sustainable agricultural practices and livelihood diversification. This comprehensive approach not only promotes sustainable productivity, resilience, and emissions reduction, but also addresses food security and development goals. By incorporating techniques such as conservation agriculture, agroforestry, sustainable intensification, and sustainable land management, we can ensure the well-being of both present and future generations. Additionally, sustainable agricultural practices serve as a bridge between on- and off-farm activities, providing smallholder farmers with the opportunity to pursue off-farm opportunities while still prioritizing the non-economic aspects of their lives. With the potential to improve household welfare and reduce vulnerability to the impacts of climate change, these practices offer a promising solution for a brighter, more sustainable future.

The implementation of Structural Adjustment Programs (SAPS), heavily relies on the involvement of both Government and development partners (Ehiakpor, 2021). However, many efforts to introduce innovative approaches in agriculture often fall short in achieving widespread success, often due to a lack of clear organizational strategies for expansion. This is especially true for more complex innovations, which require significant customization to meet the specific needs of different client groups in varying contexts (Makate, 2019). As a result, the traditional approach of viewing SAPs as a one-time intervention has been challenged, as the complexities involved in implementing these interventions make it difficult for institutions to scale-up in terms of both scope and design.

According to Rogers' theory of diffusion of innovations (1983), there is more to an innovation's potential than just its complexity. It also depends on factors such as relative advantage, trial-ability, and visibility of results. In simpler terms, an innovation must offer perceived benefits compared to previous ideas, be easily tested and experimented with, and show tangible results. This is where SAPs (Sustainable Agricultural Practices) come into play, as they possess all these qualities and have the potential to influence widespread adoption among farming communities.

The study further suggests that successful scaling up of SAPs relies on the societal structure and its values and beliefs. It is not just about the innovation itself, but also about the relationships and norms within a community. Informal networks, norms, and values all play a crucial role in the success of scaling up SAPs, as shown in various studies (Kirina et al., 2022; Vernooy & Bouroncle, 2019; Westermann et al., 2018).

In short, the potential of an innovation goes beyond its complexity. It is a combination of various factors, including its perceived advantages, ease of trial and experimentation, and visible results. And when it comes to SAPs, their success lies not just in their own attributes, but also in the societal structures and values that support their adoption and scaling up.

Transforming households with innovation requires more than just individual rationality. While factors like knowledge, attitudes, and resources play a role, they also create a divide between potential and non-potential adopters. But what happens when unexpected individuals join the ranks of adopters? This phenomenon, known as 'over-adoption,' is often seen as a negative consequence of technological diffusion. However, a different perspective sees it as a positive spill-over effect. In this view, over-adoption is not a lack of control, but rather a lack of generalization. It recognizes that even non-beneficiaries can be affected by the vertical scale-up approaches and become potential adopters. Ultimately, the spill-over effect holds more weight than over-adoption, as it ensures that both direct and indirect beneficiaries reap the same benefits.

Despite the potential benefits of scalability, current research on SAPs lacks quantitative evidence and instead relies on theoretical frameworks. This lack of statistical emphasis raises concerns about the validity of the findings, as they may not fully consider the differences between various groups impacted by the intervention. In other words, there is a danger of falling into the composition fallacy, where the overall results do not accurately reflect the specific needs and outcomes of direct and indirect beneficiaries. Without a comprehensive understanding of these differences, the effectiveness of scaling up SAPs remains uncertain, with case studies providing the primary basis for analysis.

The goal of this study is thus to investigate whether the FoodMa program has any spillover effects on non-beneficiaries. In order to do so, the study poses several research questions: (i) What factors influence participation in climate resilient programs? (ii) How do these factors impact sustained adoption of SAPs? (iii) Is there a direct correlation between FoodMa and sustained adoption? (iv) Can sustained adoption of SAPs improve resilience to food shocks? The study defines sustained adoption as consistent practice for the past three years, following previous research by Dillon et al. [14], Amadu et al. [16], and Mgomezulu et al. [12]. Additionally, farmers must maintain or not decrease the area of land under the practice, as noted by Bell et al. (2018). As a result, this study makes two significant contributions to the literature. Firstly, it adds to the limited research on the scalability of climate-resilient practices, providing valuable insight into the long-term benefits of spillover effects of SAPs, which is crucial given the cost-effectiveness concerns surrounding agricultural interventions in Malawi. Secondly, it sheds light on how to assess the sustainability and assumed effects of agricultural climate-resilient innovations, while also considering potential program self-selectivity bias.

2. Materials and methods

2.1. Study area

The Sustainable Food Systems Program (FoodMa) is making a positive impact in Malawi, specifically in the areas of Mzimba, Kasungu, and Mchinji which have been heavily affected by climatic variability. Working alongside the Lilongwe University of Agriculture and Natural Resources, the FoodMa program is dedicated to promoting sustainability by introducing innovative agricultural technologies. Through the guidance of extension workers and SAPs trainings, project beneficiaries are taught essential skills and are provided with hands-on demonstrations on effective farming practices. This holistic approach aims to enhance the sustainability of food systems in Malawi and create a brighter future for its people.

In Mzimba, farmers primarily cultivate maize and tobacco, contributing significantly to the region's agricultural success. However, in recent years, the FoodMa project has been making waves by focusing on improving maize production in all three districts. This initiative has brought new opportunities for farmers in the district, leading to increased yields and economic growth.

Mzimba's fertile soils, ranging from light-to-medium textured sandy-loam to loamy, provide the perfect conditions for agriculture. With moderate drainage and an average temperature range of 15.5 °C–19.8 °C, the district experiences a pleasant and comfortable climate. The hottest months are in November, with temperatures reaching up to 33 °C, while the coldest month is June, with temperatures dropping to 0 °C–10 °C.

The district's rainfall patterns are also noteworthy, with an annual precipitation range of 1.63 mm in September to 615.64 mm in January, averaging at 177.87 mm. These weather conditions have proven to be ideal for the success of the FoodMa project, which was implemented in five Extension Planning Areas (EPAs): Kazomba, Manyamula, Bwengu, Engutwini, and Mpherembe. These EPAs were the primary data collection areas for the current study, further highlighting the significant impact of the FoodMa project on the district's agricultural development.

Kasungu, covering an expansive 7878 square kilometers, boasts a population of approximately 842,953 people. The district enjoys a moderate climate, with temperatures ranging from 16 °C to 33 °C. However, October brings scorching heat, with an average temperature of 31.55 °C. The district experiences varying levels of precipitation, with an average of 125.18 mm per year. Surrounded by the districts of Mchinji and Dowa, Kasungu offers a diverse and welcoming community. Our research for the FoodMa project focused on the Santhe, Lisasadzi, Chipala, and Kaluluma EPAs, where we implemented the Sustainable Food Systems project.

Mchinji boasts an impressive size of 3356 square kilometers and a population of over 600,000 individuals. Its climate is a mix of warm and cool, with temperatures ranging from 10 °C to 30 °C throughout the year. Interestingly, October sees the highest temperatures, reaching an average of 29.46 °C, while July experiences the coldest weather at 11.15 °C [17]. Mchinji's annual rainfall is equally diverse, with a low of 1.82 mm in September and a high of 373.15 mm in January, averaging at 116.89 mm. The FoodMa project, a successful initiative, was skillfully executed in four EPAs - Chiwoshya, Mikundi, Kalulu, and Nkanda (Table 1).

Fig. 1, shows a detailed map of the study areas and EPAs involved in the FoodMa project. With the help of advanced ArcGIS software, the map paints a clear picture of the exact locations being studied.

Table 1
Characteristics of study areas under FoodMa.

District	Precipitation Range (mm)	Avg Precipitation (mm)	Avg Temperature Range
Mzimba	1.63 to 615.64	177.87	15.5 °C–33 °C
Kasungu	1.95 to 399.6	125.18	16 °C–33 °C
Mchinji	1.82 to 373.15	116.89	10 °C–30 °C

2.2. Theoretical framework

2.2.1. Utility maximization theorem

The household utility can best be demonstrated in a household utility which allows participating farmers in agricultural projects such as FoodMa to maximize their benefits while considering their unique characteristics, institutional factors, and agro-ecological factors. As Kassie et al. [18] concluded, this model is all about optimizing the participation experience for these households as shown below;

$$U_{it} = (\eta_{it}, h_i)\ for\ t = 1, 2, 3 \tag{1}$$

where U_{it} is the attached utility to be derived by household i from participating in a climate resilient program at time t, η_{it} presents institution like access to extension, trainings, field demonstrations, credit and agro-ecological factors like three year average rainfall and temperature data; h_i presents the household characteristics like age, gender, education level, ownership of assets among others. As such, if the farming household perceived utility to be derived from participating in FoodMa project is less than the perceived utility from not participating in the Foodma project, then a household will choose not to participate. If it is postulated that P denote the observable decision for a farming household i to participate in the FoodMa project. Furthermore, if U_1 represent the utility from participation and U_0 to denote the utility from non-participation, then P will equal to 1 if the farming household decides to participate and 0 otherwise.

Thus, it is observed that:

$$P = 1\ if\ U_1 > U_0 \tag{2}$$

$$P = 0\ if\ U_1 < U_0 \tag{3}$$

To that extent, following Wooldridge [19], the linear random utility model can be presented as follows;

$$U_{it} = \delta X_{it} + \varepsilon_i \quad for\ t = 1, 2, 3 \tag{4}$$

where U_{it} is the expected utility from participating in FoodMa; X_{it} is the vector of observed variables relating to household, institutional and agro-ecological characteristics; δ is the vector of unknown parameters which are to be estimated; and ε_i is the stochastic error term which captures the unobservable attributes that affect utility.

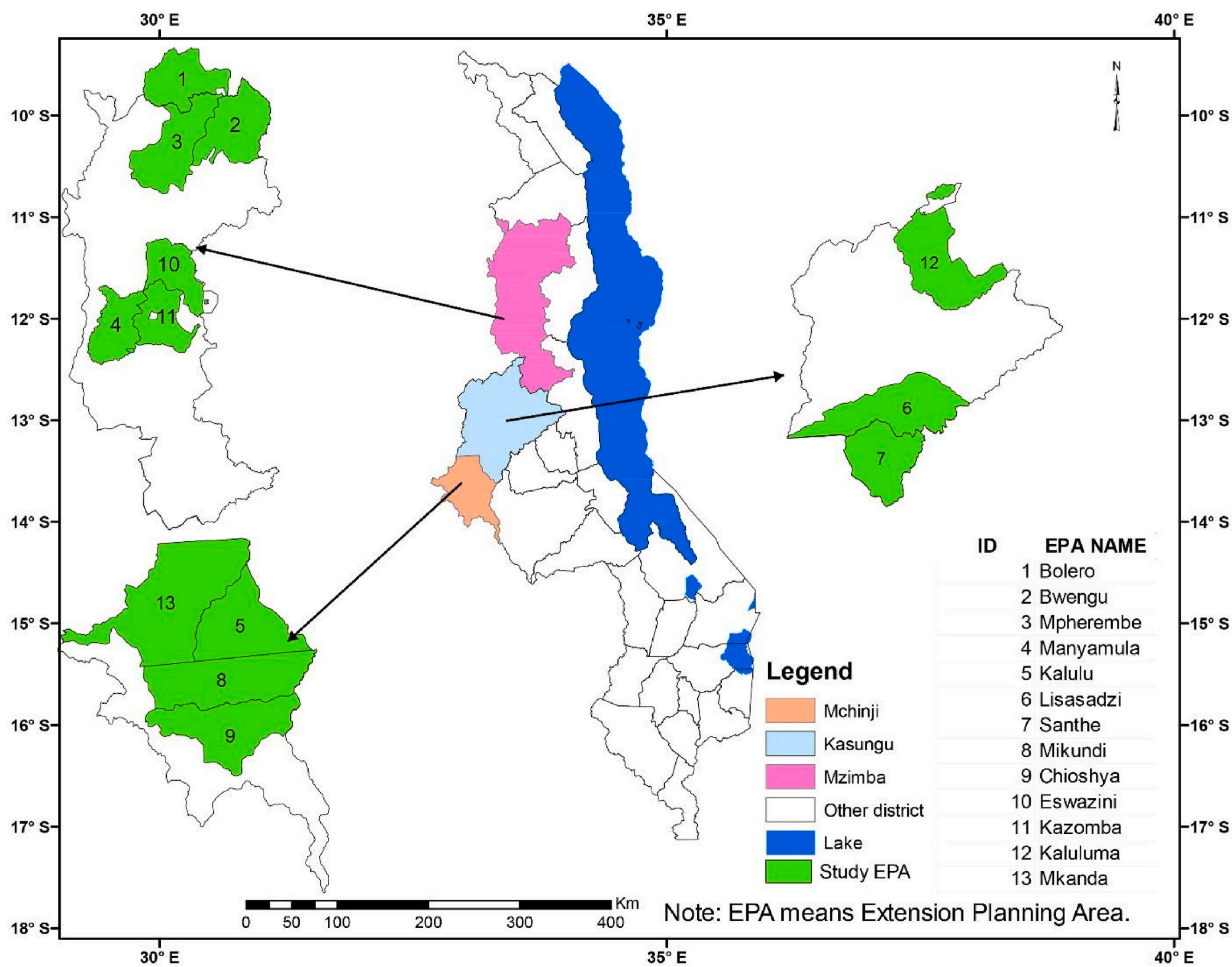

Fig. 1. Map of Malawi showing FoodMa study areas in the districts of Mchinji, Kasungu and Mzimba.

2.2.2. Social network theory

The Social Network Theory has gained popularity due to its belief that spillover effects are influenced by social connections. To truly understand the impact of the FoodMa project, this study has adopted the social network theory. First introduced by Mitchell in 1974, this theory delves into the diverse social connections within society that can shape individual behavior. These networks can be defined as the intricate structures that facilitate communication within a society [20]. These connections are often reinforced by societal norms and attitudes. The theory also recognizes the significance of clusters, which are groups of individuals with shared beliefs and interests, in driving participation in social initiatives and programs [20]. Mitchell [21] further outlines three key elements of social interactions: communication content, normative content, and transaction content. In this study, the focus is on communication content as the primary driver of information spillover regarding Sustainable Agriculture Practices (SAPs). According to Mitchell [21], communication content is primarily concerned with the diffusion of technology and the spread of new ideas in society. However, the study acknowledges that these new ideas and information often flow through similar network locations and within networks of individuals with similar socioeconomic characteristics [22]. As a result, the study expects non-participating households with similar socioeconomic backgrounds and facing similar agro-ecological conditions to be influenced by participating households in their response to climatic shocks and their food security status.

To understand this theory better, the bandwagon effect is further adopted as an example. According to this effect, people tend to participate in a voting poll because they see others doing so [23]. In other words, their decision to participate is heavily influenced by the actions of others. This is beautifully illustrated by Gavious and Mizrahi [24] as they explain how climatic shocks can impact a household's food security status, and in turn, influence their decision to participate in the poll.

ng Gavious & Mizrahi [24], we present this as follows:

$$Y_{i(t+\Delta t)} = Y_{i(t)} + \beta Y_{i(t)} Y_{0(t)} \Delta t \tag{5}$$

$$Y_{0(t+\Delta t)} = Y_{0(t)} - \beta Y_{i(t)} Y_{0(t)} \Delta t \tag{6}$$

where $Y_{i(t)}$ and $Y_{0(t)}$ present the number of sustained adopters and non-adopters of SAPs at a specific time period in a society; $(t+\Delta t)$ present the time period of the respective number of sustained adopters; and β presents the respective rate of sustained adoption of SAPs which is influenced by the given preferences of non-adopters, $Y_{0(t)}$.

The theory hence postulates that $Y_{i(t)}+Y_{0(t)} = N$. This implies that the total sample can be divided into two main groups of sustained adopters and non-adopters over the given time period. Nonetheless, the theory does not conclude that adoption is an end to the dissemination channel but also considers withdraw and discontinuance as possibilities [25]. This further explains the need for considering sustained adoption and can be presented as follows:

$$Y_{i(t+\Delta t)} = Y_{i(t)} - \alpha Y_{i(t)} \Delta t \tag{7}$$

$$Y_{0(t+\Delta t)} = Y_{0(t)} + \alpha Y_{i(t)} \Delta t \tag{8}$$

In this current re-parameterization, α gives the rate of discontinuance and is influenced by individual familiarities. Consolidating both possible outcomes of the technology dissemination channel, we present the equation as follows:

$$Y_{i(t+\Delta t)} = Y_{i(t)} + \beta Y_{i(t)} Y_{0(t)} \Delta t - \alpha Y_{i(t)} \Delta t \tag{9}$$

$$Y_{0(t+\Delta t)} = Y_{0(t)} - \beta Y_{i(t)} Y_{0(t)} \Delta t + \alpha Y_{i(t)} \Delta t \tag{10}$$

This implies that the SAPs are expected to flow from the initial adopters which are the FoodMa project participants and then spillover to the non-participants who share similar socio-economic and agro-ecological features to the FoodMa participants.

2.2.3. Weak instrument test

The effectiveness of the instrument used in this study is yet to be determined, as relying solely on theory is not enough to establish its validity [19]. However, the study proposes that the proportion of agricultural plots (participation intensity) in a specific area under SAPs has a positive impact on program participation, but does not directly affect sustained adoption or resilience scores [13,14,16]. Instead, it indirectly influences resilience through sustained adoption of the SAPs [19]. To assess the validity of the instrument, the study follows the method of Kubitza and Krishna [26] and Amadu et al. [16], using the zero-first-stage test. According to Li et al. [27], the effect of the instrument is zero in the reduced form participation equation, which satisfies the exclusion restriction. To confirm this, the null hypothesis of $\delta = 0$ is tested against the alternative hypothesis of $\delta \neq 0$. The strength of the identified instrument is then assessed using Stata user written command of weakiv. The study utilizes both the ivtobit model and a robust test for IV. The results show that the null hypothesis of weak instruments can be rejected, as the wald statistic is significant at a one percent level (Table 3). The robust test for IV also yields significant results, with ARChi2(2)-27.28, p = 0.000 and Wald test Chi (2)-14.23, p = 0.00026, respectively.

2.2.4. The data

The information we gathered was from a diverse and comprehensive group of 2100 households, chosen at random from 349 Enumeration Areas (EAs) in the districts of Mzimba, Kasungu, and Mchinji. Our sampling framework mirrors the recent Fifth Integrated Household Survey [28]. We collected quantitative data from 1050 households in FoodMa project areas and 1050 households in Non-FoodMa sites within the same districts. To supplement this data, we also gathered qualitative data through Focus Group Discussions and Key Informant Interviews with extension workers from the randomly selected EAs. Our selection process was carefully designed to prevent any biases. Additionally, we made sure to choose EAs with similar agro-ecological characteristics to the FoodMa sites and those earmarked by local extension officers as potential future FoodMa sites. While it is possible for Non-FoodMa sites to have adopted the Sustainable Agricultural Practices (SAPs) over the past decade, our focus on FoodMa sites allows for a deeper understanding and awareness of these practices. This knowledge is essential for promoting sustainability in the adoption of SAPs, which is a new concept in this context.

The study conducted by Bachewe et al. [29] took into account various factors that greatly influence conservation agricultural practices, including rainfall, temperature, soil type, and perception of soil quality. As highlighted by Mukhtar [30], Amadu et al. [16], and Dillon et al. [14], the perception of soil quality was measured by farmers based on its texture and fertility, categorized as poor, fair, or good. In order to accurately analyze the data, three-year average monthly rainfall and temperature data were obtained from CEDA (Center for Environmental Data Analysis) for the districts and EAs included in the study. The GPS coordinates were then used to merge the farmer characteristics with the collected data, as suggested by Dessy et al. [31].

Following NSO (2020), proportional sampling to size of the districts was adopted and hence we calculate sample weights which is the inverse of the probability of selecting farmers in the districts.

Table 1 presents the sample for the study.

2.3. Empirical framework

2.3.1. The recursive bivariate probit (RBP) model

The Foodma project aims to train farmers on climate resilient practices, with the ultimate goal of promoting sustained adoption of Sustainable Agricultural Practices (SAPs). In order to measure the effectiveness of the project, the study takes into account both farmer participation and non-participation in the Foodma project activities. This allows for a comprehensive evaluation of the impact of project

Table 2
Proportion Sampling to Size in the one Northen and two Central [Three] Districts of Malawi.

District	Number of EAs	Number of Households (Rural)	Average Number of HHs/EA	Sampled EAs (pps)	Beneficiary HHs	Non-Beneficiary HHs	Final Sample
Mzimba	865	188,802	131	144	432	432	864
Kasungu	799	166,032	208	133	399	399	798
Mchinji	438	130,437	298	73	219	219	438
Total	2102	485,271	637	349	1050	1050	2100

Abbreviations: HH: Households, EAs: Extension Area, FoodMa: … … … … … … … …

Table 3
Social Demographic Characteristics for the sampled households.

Variable	Measurement	Sustained Adoption	Sustained Adoption	Sustained Adoption	FoodMa	FoodMa	P-Values
		Organic Manure n = 818	Mulching n = 498	Pit Planting n = 154	Participants n = 1050	Non-participants n = 1050	
HH Size	Persons	4.49 (1.76)	4.4 (1.58)	4.7 (1.53)	4.4 (1.6)	4.2 (1.7)	0.000
HH education	Effective years spent in school	7.3 (3.5)	6.5 (4.05)	5.7 (4.2)	7.1 (3.8)	6.4 (3.7)	0.000
HH Age	Years	43.5 (13.9)	44.5 (12.7)	45.7 (14.6)	43.4 (13.8)	43.1 (15.5)	0.616
Land size	Acre	3.2 (2.9)	3.3 (3.0)	3.4 (4.7)	3.21 (2.70)	2.70 (2.70)	0.000
Tropical Livestock Units (TLU)	Number	0.59 (1.4)	0.62 (1.42)	0.63 (1.5)	0.59 (1.4)	0.30 (0.8)	0.000
3-year average temperature	Degrees Celsius	21.1 (0.96)	21.0 (1.03)	21.0 (1.1)	21.16 (0.96)	21.16 (0.95)	0.962
3year average rainfall	Mm	80.8 (5.62)	80.7 (5.7)	81.6 (6.1)	80.9 (5.6)	80.8 (5.7)	0.488
Household income (logged)	Total expenditure	10.86	10.59	10.86	10.43	10.21	0.000
Soil type (%)	Sandy	11.76	13.78	18.53	14.61	13.89	0.214
	Loam	32.57	45.67	38.79	36.37	38.19	0.396
	Sandy Loam	48.37	32.20	38.36	42.55	40.77	0.418
	Clay	7.30	8.36	4.31	6.47	7.14	0.548
Perception of soil fertility (%)	Poor	12.64	28.33	37.93	16.86	18.06	0.479
	Fair	68.41	52.94	44.83	65.29	62.60	0.206
	Good	18.95	18.73	17.24	17.84	19.35	0.385
Radio ownership	Yes (1/0)	0.233	0.191	0.192	0.227	0.145	0.000
Savings group membership	Yes (1/0)	0.260	0.260	0.176	0.239	0.101	0.000
Farmer club membership	Yes (1/0)	0.497	0.538	0.438	0.531	0.260	0.000
Attended SAPs field demonstrations	Yes (1/0)	0.793	0.877	0.893	0.839	0.573	0.000
Listened SAPs Radio program	Yes (1/0)	0.825	0.919	0.938	0.863	0.646	0.000
Received SAPs training	Yes (1/0)	0.786	0.842	0.885	0.861	0.294	0.000
Extension visit in last 12 months	Yes (1/0)	0.687	0.752	0.790	0.751	0.495	0.000
rCSI	Index (0–53)	9.2 (0.4)	6.77 (0.4)	5.52 (0.7)	8.11 (0.8)	9.65 (0.98)	0.002

Standard deviation in parenthesis.
Abbreviations: HH: Households, SAPs: Sustainable Agriculture Practices.

involvement on the sustained adoption of SAPs.

To ensure accurate results, the study focuses on farmer households residing in the Foodma project areas who have either participated or not participated in the project. These households are the true beneficiaries of the project and their adoption of SAPs is of utmost importance.

In order to eliminate any potential influence from outside factors, the study also takes into consideration the presence of other similar projects in the area. This allows for a clear analysis of the impact of the Foodma project alone on the adoption of SAPs.

Through a thorough and comprehensive approach, the study aims to showcase the true impact of the Foodma project on the adoption of sustainable agricultural practices. By including both participants and non-participants in the study, it provides a well-rounded understanding of the project's effectiveness.

The FoodMa project's selection of project beneficiaries and sites was not a random process, as noted in the study. This was further influenced by the involvement of key local stakeholders such as lead farmers and extension workers, who played a crucial role in identifying beneficiaries and disseminating project information. However, the involvement of these stakeholders could potentially create bias in the estimation process, as factors like the farmers' relationship with them, entrepreneurial skills, and personal motivation could affect their participation in the project. This highlights the importance of considering potential endogeneity bias in the project's outcomes [19].

To properly estimate the direct and spillover effects, the study follows Wooldridge [19] and employs a Recursive Bivariate Probit (RBP) model which is presented as follows:

$$F = 1 \ if \ F_p^* > F_{np}^* > 0; \ F = 0 \ if \ F_{np}^* > F_p^* > 0 \quad (11)$$

where F is the decision to participate in the FoodMa project; F_p^* is the latent variable indexing the utility realized from participating in the FoodMa project; and F_{np}^* is the latent variable indexing the utility realized from not participating in the FoodMa project. Further, following Greene [32], participating in the FoodMa project can be explained as a function of socioeconomic, institutional and agro-ecological factors:

$$F_{it} = \beta X_{it} + \delta Z_{it} + \tau_i \quad for \ t = 1, 2, 3 \quad (12)$$

where F_{it} is equal to 1 if a farming household decides to participate in the FoodMa project in time t and 0 otherwise; X_{it} presents a vector of socioeconomic, institutional, agro-ecological factors; β is a vector of parameters to be estimated; Z_{it} is a vector of instrumental variable (which is the proportion of crop fields in the EA under the SAP) and τ_i is the stochastic error term.

To measure the direct effects of project participation on sustained adoption, S_i, if a farming household participated in the FoodMa project, we present the equation as follows:

$$S_{it} = \vartheta F_{it} + \gamma X_{it} + \varepsilon_i \quad for\ t = 1, 2, 3 \tag{13}$$

where S_{it} equals 1 if the farmer sustainably adopted SAPs and 0 otherwise; F_{it} presents farmer participation in the FoodMa project; X_{it} is a vector of socioeconomic, institutional and agro-ecological factors; ϑ and γ are parameters to be estimated; and ε_i is the error term robust to heteroscedasticity [19]. As such, the stochastic error terms τ_i and ε_i are assumed to follow a bivariate normal distribution which can be expressed as follows:

$$cov(\tau_i, \varepsilon_i) = \begin{pmatrix} 1 & \rho \\ \rho & 1 \end{pmatrix} \tag{14}$$

where ρ represents the RBP correlation coefficient of the unobserved covariates presented in first and second stages of the RBP [27]. A significant ρ will imply that there exists unobserved heterogeneity due to the correlation of the error terms τ_i and ε_i, hence the use of the RBP to solve for endogeneity [27]. Nonetheless, our use of the instrumental variable approach further eliminates any possible self-selectivity bias [19].

To model spillover effects, we estimate another RBP that models non-participation for non-participating households living in close geographical and social proximity as participating households [33]. These can be presented as follows:

$$S_{it} = \beta NP_{it} + \varphi X_{it} + \varepsilon_i \quad for\ t = 1, 2, 3 \tag{15}$$

where S_{it} equals to 1 if a non-participating household sustainably adopts SAPs and 0 otherwise; NP_{it} equals 1 if the farming household is a non-participant and hence β measures the spillover effect. Nonetheless, the direct and spillover effects on sustained adoption of SAPs are presented through the Average Treatment effect on the Treated (ATT) and the Average Treatment effect on the Untreated (ATU) following Li et al. [27] and are presented as follows:

$$ME = Exp\ [(S_i)|P_i > 1] \tag{16}$$

$$ATT = E\ \{[P_i = 1] - [P_i = 1]\} \tag{17}$$

$$ATU = E\ \{[P_i = 0] - [P_i = 0]\} \tag{18}$$

where $Exp\ [(S_i)|P_i > 1]$ denotes sustained adoption (S_i) of SAPs conditional on participation (P_i) in the FoodMa project; $E\ [P_i = 1]$ provides the expected probability of sustained adoption for participants; $[P_i = 1]$ presents expected probability of non-adoption of participants; $E\ [P_i = 0]$ presents expected probability of sustained adoption of non-participants; and $E\ [P_i = 0]$ presents expected probability of non-adoption of non-participants.

2.3.2. The two-stage predictor substitution (2SPS)

We now take a closer look at how sustained adoption can impact the resilience of farming households to food shocks. At this stage, we will now be using the reduced coping strategy index (rCSI) as our measure of food security, which was specifically designed to be applicable in various contexts [30]. This index takes into account a range of behaviors and their severity, providing a standardized approach to assessing food security. The rCSI consists of five commonly used coping strategies, each with a designated severity weighting: eating less-preferred foods (1.0), borrowing food or money from friends and relatives (2.0), limiting portions at mealtime (1.0), limiting adult intake (3.0), and reducing the number of meals per day (1.0). By examining the effects of sustained adoption on these strategies, we can gain a better understanding of how it contributes to the overall resilience of farming households.

At this point, we consider the statistical aspect of the problem of endogeneity which often arises due to omitted confounding variables and the pesky self-selectivity bias. But fear not, as we have a powerful tool at our disposal - the instrumental variable regression. Our approach involves a two-stage predictor substitution (2SPS) regression, where we first estimate reduced form regressions and use the results to generate predicted values for the endogenous variables. In the second stage, we conduct a regression for the outcome of interest, replacing the endogenous variables with their predicted values. To make our predictions, we utilized the power of probability models, specifically probit models for each SAP adopted. This ensures a more accurate and reliable analysis.

Because rCSI contain values ranging from 0 to 56 (higher values imply that households are more prone to food shortages), it follows a double truncation with lower and upper limit. This violates the normal distribution assumption of the OLS and necessitate the use of tobit model [19]. Following Tobin [34], the rCSI can be best presented as a latent variable specification problem as follows:

$$\text{First Stage}: P_{ijt} = \delta_0 + \sum_{j=0}^{j} \delta_j Z_j + w_j \quad for\ t = 1, 2, 3 \tag{19}$$

$$\text{Second Stage}: R_j^* = \delta_0 + \sum \delta_j Z_j + \gamma_j\ M_{ijt} + w_j \quad for\ t = 1, 2, 3 \tag{20}$$

where R_j^* is the latent variable indexing reduced coping strategy index for the households; P_{ijt} presents sustained adoption of SAPs; δ_j and γ_j are vectors of unknown parameters to be estimated; Z_j is a vector of socioeconomic, institutional and agro-ecological factors; M_{ijt} depicts predicted values of SAPs and w_j is the error term that is independent and normally distributed $N(0, \sigma_w^2)$.

3. Results and discussion

3.1. Descriptive statistics

Table 2 presents descriptive statistics of the farming households that were included in the study. The average household size was four individuals, with the heads of these households having spent an impressive 6.4–7.1 years in school. The average age of the household heads was 43 years, providing a diverse range of experience and knowledge. When it came to land ownership, it was found that FoodMa households owned an average of 3.2 acres, while non-FoodMa households owned an average of 2.7 acres. The agro-ecological features of these areas were also intriguing, with an average annual rainfall of 88 mm and an average temperature of 21.2 °C. Interestingly, 65.2 percent of FoodMa participants and 62.6 percent of non-participants believed that their soils were of fair quality. A closer look at the participants also revealed that 22.7 percent of FoodMa households owned a radio, compared to only 14.5 percent of non-participants. Additionally, a significant 86.1 percent of FoodMa participants had received training on SAPs, while only 29.4 percent of non-participants had the opportunity to do so. This trend continued as it was discovered that 75.1 percent of FoodMa participants had received extension visits within the past 12 months, while only 49.5 percent of non-participants had. Finally, the non-participants had a higher rCSI value of 9.65, compared to the value of 8.11 recorded by the participants, which was significant at 1 percent. These results provide valuable insights into the differences between FoodMa and non-FoodMa households, highlighting the impact of participation in the program.

3.2. Determinants of participation in Foodma project

Using the RBP model, we identify key determinants and their impact on participation, which you can see in Table 4. The model was found to be significant at an impressive 1 percent level, and the Wald test of zero error correlation (rho = 0) was also rejected at 1 percent, confirming that the model is a strong fit for explaining participation in FoodMa and sustained adoption [19]. Interestingly, we found that aside from the

Table 4
Factors that Determines participation in FoodMa projects among Smallholder Maize Farmers.

FoodMa Participation	Coefficient	Marginal effects	Std Error
HH_Size	0.014	−0.005	0.005
HH_Education	0.011	−0.003	0.002
HH_sex	0.084	0.022	0.020
HH_Age	0.024	0.011	0.003***
Age2	−0.000	−0.000	0.000***
Off-farm	0.270	0.023	0.046
Children	0.027	0.029	(0.014)**
HH_Land	0.013	0.005	0.003
Radio	0.118	−0.010	0.019
Average temp	0.123	−0.003	0.019
Average rain	−0.001	−0.001	0.002
TLU	0.109	0.026	0.009***
Soil type			
Loam soil	−0.220	0.052	0.024**
Sandy Loam	−0.023	0.025	0.025
Clay	−0.264	0.032	0.039
Soil quality			
Fair	0.072	−0.127	0.025***
Good	−0.120	−0.136	0.029***
Floods	−0.084	−0.078	0.032**
Savings club membership	0.578	0.129	0.020***
SAPs Demo	0.641	0.203	0.020***
SAPs Radio programs	0.401	0.129	0.022***
Participation intensity (IV)	1.154	0.219	0.003***
Diagnostic			
Log pseudolikelihood	−3046.68		
Wald chi2 test	953.82***		
Rho	−0.666*		
Wald test of rho = 0 chi2 (1)	14.386		
Prob > chi2	0.0002		
/atanrho	−0.327		

*$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.
Abbreviations: HH: Households, TLU: Tropical Livestock Units.

selection process, other factors such as the age of the household head, Tropical Livestock Units (TLU) owned, soil type of farmers' plots, savings club participation, radio ownership, and SAPs field demonstrations all played a role in self-selection into the program. For example, we discovered that households with older heads were more likely to participate in FoodMa, but there was a tipping point where increasing age actually decreased the chances of participation. This makes sense since active participation in projects like this requires time and energy, which may be more readily available for those in the younger age group.

Through the FoodMa project, it was discovered that an increase in livestock value resulted in a 2.6% higher chance of participating. This aligns with the research conducted by Teklewold et al. [35], who also found that acquiring livestock had a positive impact on the adoption decisions of rural Ethiopian farmers. As pointed out by Atanga et al. [36], livestock offers a multitude of benefits that entice farmers to adopt sustainable agricultural practices. In fact, Atanga et al. [36] notes that livestock production is a major source of income for smallholder farmers in Africa. As a result, households with higher incomes are more likely to embrace SAPs compared to those with lower incomes.

Unlocking the full potential of FoodMa projects requires a key ingredient: loam soil plots. According to previous research by Adesida et al. [37], owning plots with loam soils significantly increases farmers' likelihood of participating in these projects. The reason? Loam soils have a unique ability to retain nutrients, making them ideal for enhancing soil fertility. This not only motivates farmers to protect the quality of their land, but also encourages them to adopt sustainable agricultural practices (SAPs). Through Focus Group Discussions (FGDs), it was discovered that farmers with loam soils were more eager to participate in the FoodMa project. This was supported by the findings of other scholars who found that field demonstrations and membership in savings clubs or radio listening groups were key factors in influencing farmers' interest in SAPs ([38,39]; et al., 2017). Additionally, the proportion of agricultural plots under SAPs in a given area was found to have a positive impact on participation, providing further evidence of the strong link between participation intensity and success [15,40]. In other words, by improving access to loam soils and promoting SAPs through various channels, the FoodMa project has the potential to not only enhance soil fertility, but also increase farmers' participation and overall success. It's a win-win situation for all involved.

3.3. Factors influencing sustained adoption of SAPs

In the RBP model, the second stage looks at the factors that played a role in the continued implementation of SAPs among the households included in the study (refer to Table 5). An important aspect to note is the recursive nature of the participation variable in this stage. It was found that participation in the FoodMa project had a significant positive impact on the sustained adoption of all SAPs, with a significance level of 1 percent. This means that farmers who were part of the project were more likely to continue implementing SAPs compared to non-participants. Furthermore, interviews with extension officers provided further evidence of this finding, as the project's trainings not only equipped farmers with the necessary knowledge and skills to implement the practices on their fields, but also highlighted the benefits of adopting these practices (see Table 6).

In order to promote sustained adoption, the study has included various covariates as controls. Among these, project specific factors such as SAPs field demonstrations have shown a significant impact on increasing the likelihood of sustained adoption of mulching. Additionally, listening to SAPs radio programs has also proven to be a key factor in promoting sustained adoption of mulching and pit planting. These findings are in line with previous research by Mgomezulu et al. [12] which also highlights the importance of project specific factors in reducing the risk of dis-adoption of SAPs. The success of field demonstrations can be attributed to the hands-on learning approach which allows farmers to gain practical skills and easily implement them. This is further supported by Amadu et al. [16] who emphasize the need for training programs to improve farmer understanding and adoption of agricultural technologies. Similarly, Dillon et al. [14] suggests that providing practical demonstrations can greatly enhance farmer uptake of agricultural interventions. Other significant determinants of sustained adoption include household size, household head education, age and gender, off-farm activities, soil type, soil quality, and membership of savings clubs.

Household size is a crucial factor when it comes to food security. It plays a significant role in the distribution of resources within family. A smaller household size is more efficient in managing resources and ensuring food security compared to a larger one. This is because a larger household has a higher number of members to feed, making it more challenging to allocate resources effectively. On the other hand, education also has a direct impact on food security. With increased education, individuals gain valuable knowledge and make informed decisions when it comes to Sustainable Agriculture Practices (SAPs), nutrition, and diversifying their income through off-farm activities. This ultimately leads to improved food security for the household [41]. Another critical factor that affects food security is the size of the land owned by farmers. The size of land determines the level of production and the farmers' ability to have a variety of SAPs, resulting in higher yields and improved food security [42]. Furthermore, owning a radio can also contribute significantly to food security. By providing access to weather forecasts and information on suitable SAPs for a particular farmer, radios can greatly increase yields and ensure food security [43]. However, certain factors can negatively impact food security levels in households. These include owning a smartphone, having loam soils, and experiencing floods and dry episodes. Owning a smartphone may seem like a positive aspect, but it can actually hinder food security by distracting individuals from their farming responsibilities. Loam soils, floods, and dry episodes are also significant environmental factors that can affect

Table 5
Factors that are influencing sustained adoption of Sustainable Agricultural Practices among smallholder maize farmers.

Variables	Sustained Mulching		Sustained Organic		Sustained Pit Planting	
	dy/dx	Std Error	dy/dx	Std Error	dy/dx	Std Error
FoodMa Participation	1.499	0.499***	1.988	(0.047)***	1.300	0.398***
Controls						
HH_Size	−0.045	0.024*	0.022	0.018	0.092	0.028***
HH_Education	−0.028	0.010***	0.019	0.008**	−0.050	0.012***
HH_sex	0.036	0.091	−0.072	0.068	−0.087	0.097***
HH_Age	0.038	0.017**	−0.010	0.011	−0.041	0.017***
Age2	−0.000	0.000	0.000	0.000	0.000	0.000***
Off-farm	−0.163	0.248	−0.076	0.154	−0.962	0.466**
Children	0.134	0.064**	0.007	0.050	−0.152	0.077**
HH_Land	0.012	0.011	−0.003	0.009	0.008	0.015
Radio	−0.188	0.087**	−0.019	0.068	−0.040	0.102
Average temp	−0.138	0.030	−0.031	0.032	−0.116	0.039
Average rain	−0.006	0.005	−0.005	0.005	0.010	0.007
TLU	0.030	0.036	0.018	0.028	0.027	0.032
Soil type						
Loam soil	0.530	0.106***	−0.022	0.097	0.110	0.122
Sandy loam	0.157	0.107	0.289	0.094***	0.010	0.119
Clay	0.464	0.152***	0.210	0.146	−0.208	0.200
Quality						
Fair	−0.819	0.102***	0.293	0.090	−0.708	0.111***
Good	−0.674	0.133***	0.214	0.105	−0.528	0.142***
Floods	−0.354	0.160	0.149	0.119	−0.190	0.187
Savings club	0.108	0.155	0.400	0.111***	−0.226	0.139
SAPs Demonstrations	0.465	0.190**	−0.049	0.091	0.250	0.178
SAPs Radio	0.306	0.145**	−0.076	0.082	0.306	0.163**

*$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.
Abbreviation: HH; Households, TLU: Tropical Livestock Units, SAPs: Sustainable Agriculture Practices.

Table 6
The direct and spillover effects of project participation on sustained adoption of sustainable agricultural practices Amongst smallholder maize farmers.

Participant Group	Sustained Mulching	Sustained Organic manure	Sustained Pit planting
	Effect	Effect	Effect
FoodMa (ATT)	0.451*** (0.146)	0.664*** (0.046)	0.254 (0.115)
Non-Participants (ATU)	0.573*** (0.081)	−0.258 (0.273)	0.235 (0.075)

Standard errors in parentheses.
*$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.
Abbreviations: ATT: Average Treatment effect on the Treated, ATU: Average Treatment effect on the Untreated.

agricultural productivity. Waterlogging in loam soil can impede crop growth, while floods can damage crops and disrupt the supply chain, leading to a decrease in food availability and access. And during dry episodes, such as droughts, food insecurity only worsens [44]. It is essential to address and manage these factors to ensure food security for households.

3.4. Direct and Spillover Effects of FoodMa on Sustained Adoption

The FoodMa project has proven to be a powerful force in promoting sustained adoption of SAPs, not only for its direct participants, but also for non-participants. Through the use of the RBP model, the study was able to uncover the significant impact of the project on both groups. The numbers speak for themselves - with a 45% increase in the adoption of Mulching and a staggering 66% increase in Organic farming among FoodMa participants. But the benefits don’t stop there. Even non-participants saw a remarkable 57% rise in sustained adoption of Mulching, thanks to the positive spillover effects of the project. This study truly highlights the effectiveness and reach of the FoodMa project in promoting sustainable agriculture practices.

The adoption of sustainable agricultural practices (SAPs) is crucial for the long-term success of farming communities. In a recent project, it was found that while mulching was widely accepted and practiced by both project participants and non-participants, other SAPs such as no tillage and pit planting were not embraced by non-participants. This lack of adoption could be attributed to the complexity and labor-intensive nature of these technologies compared to mulching. For example, pit planting involves precise measurements and digging, making it difficult for non-participants to learn from their fellow farmers. However, the project’s focus group discussions revealed that non-participants were eager to learn about the SAPs from their peers who were project beneficiaries. It is worth noting that most smallholder farmers in both the project and non-project areas have an average landholding size of only 3 acres per household. This makes it easier for them to adopt less costly and labor-intensive practices, such as mulching. The focus group discussions also highlighted that mulching was seen as the most affordable and sustainable farming technique compared to other SAPs. As one participant stated, “With mulching, we can use materials from our own farms, such as crop residues from previous production. This makes mulching a more feasible option compared to the tedious and costly pit planting.” It is clear that the spillover effects of the project were mainly focused on the adoption of mulching, as it was seen as the most practical and accessible technique. However, it is essential to continue educating and promoting other SAPs to ensure a more well-rounded and sustainable approach to agriculture in the community. The project’s success in promoting mulching should serve as a stepping stone towards wider adoption of other SAPs and ultimately lead to a more resilient and thriving farming community.

According to Nyakudya et al. [45], pit planting has been proven to be the top sustainable agriculture practice (SAP) for smallholder farming systems. Despite its labor-intensive nature, this method promotes water infiltration and is highly efficient in areas with low rainfall. The results of focus group discussions also support this finding, as farmers expressed their dislike for zero tillage due to the weed problem that requires the use of herbicides. This continued use of chemicals, as highlighted by Mitra et al. [46], can lead to soil pollution and is a major concern among farmers.

3.5. Spillover Effect of Sustained Adoption of SAPs on resilience to Food shocks

Table 7 illustrates the powerful impact of sustained mulching and no tillage practices on rCSI. Surprisingly, the results show that non-participants who consistently adopted mulching experienced a decrease in their susceptibility to food insecurity. In other words, those who embraced this sustainable technique were more likely to have a secure food supply compared to non-participants who did not adopt it. These findings align with previous studies that have hailed mulching as a game-changer in increasing crop yield and reducing food insecurity [47]. By improving soil fertility and water retention, mulching leads to a bountiful harvest. And as we know, a higher yield means less food insecurity. Interestingly, our focus group discussions revealed that small-scale farmers tend to gravitate towards affordable and practical agricultural practices, hence the widespread adoption of mulching among non-participants.

The success of food insecurity reduction in Malawi can be attributed to one key factor: mulching. While the implementation of Structural Adjustment Programs (SAPs) has been ongoing in the country, it's worth noting that the approach taken by the FoodMA project has been truly remarkable. Unlike other studies, this project has prioritized regular visits to project areas to continuously support and motivate smallholder farmers, whose main objective is not profit maximization. This unique aspect sets this study apart, as it recognizes the importance of constant support and guidance in the adoption process. Moreover, the strategies employed in these project areas have been so effective that it's crucial to also examine their spillover effects on non-participating households. To ensure the accuracy of the findings, the study carefully considered other factors that may impact food security, such as household size, education level, off-farm activities, land ownership, and access to a radio. The study found that these factors can all contribute to an increase in food security, while natural disasters like floods and dry spells can have the opposite effect [42].

Table 7
The Effect of sustained adoption of Sustainable Agricultural Practices on Reduced Coping Strategy Index (rCSI) of smallholder maize farmers.

rCSI	Marginal Effect (dy/dx)
Sustained Mulching	−4.503*** (1.240)
Sustained no tillage	−4.947 (2.806)
Sustained Organic farming	−2.856 (1.626)
Controls	
HH_Size	−1.106*** (0.176)
HH_Education	−0.381*** (0.082)
HH_Sex	0.421 (0.618)
HH_Age	0.133 (0.100)
Age Square	−0.001 (0.001)
Off farm	−3.087** (1.421)
Children	0.614 (0.461)
HH_Land	−0.614*** (0.461)
Radio	−1.845*** (0.655)
TLU	−0.478 (0.238)
Soil type	
Loam	−5.442*** (0.981)
Sandy Loam	1.073 (0.790)
Clay	−1.848 (1.227)
Soil Quality	
Fair	−0.945 (1.265)
Good	1.470 (1.294)
Floods	2.422** (1.128)
Dry	9.309*** (0.851)
Savings	−0.323 (1.217)
Club	−2.655*** (0.688)
SAPs Field Demonstrations	−0.736 (0.811)
SAPs radio programs	−4.542 (0.800)
SAPs training	−5.570*** (1.792)
Average rainfall	0.005 (0.041)

Standard errors in parentheses.
*$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.
Abbreviations: HH: Households, TLU: Tropical Livestock Units, SAPs: Sustainable Agriculture Practices.

4. Conclusion and recommendations

The main objective of the study was to assess the long-term impact of participating in the FoodMa project on building resilience to food shocks. In order to accurately measure the effects of the project, the study took into account any potential biases and causality relationships between the variables. Using Recursive Bivariate Probit (RBP) models, the researchers were able to evaluate both the direct effects on project participants and the spillover effects on non-participants. Additionally, the study utilized a two-stage predictor substitution approach to determine the contribution of sustained adoption of SAPs. This involved using instrumental variable probit models for each SAP and predicting adoption values in the first stage.

In the second phase of the study, the predicted values were utilized in a Tobit model that factored in the lower and upper limits of the rCSI. The results revealed compelling evidence that involvement in climate resilient programs, such as the FoodMa project, had a positive impact on sustained adoption of mulching, organic farming, and pit planting (direct effects). Furthermore, the study also found significant evidence of potential spillover effects on sustained adoption of mulching for non-participants, which in turn improved household resilience to food shocks. However, the effects of sustained adoption of no tillage and pit planting on resilience to food shocks were found to be insignificant. This study highlights the effectiveness of mulching as a sustainable agricultural practice, as it is relatively easier to implement compared to other complex techniques.

The study highlights the importance of additional factors in the successful implementation of SAPs, with a particular focus on mulching. Along with proper training and on-field demonstrations, these factors equip farmers with the necessary knowledge and skills to effectively carry out the SAPs. Additionally, education and active participation in the SAP radio program have been found to significantly increase household resilience to food shocks.

The implications of these findings are significant for policy makers. It is not enough to simply promote the adoption of Sustainable Agricultural Practices (SAPs), but it is crucial to ensure that these practices are sustained in order to improve the resilience of smallholder farming households against food shocks. The evidence is clear - programs that prioritize sustainability not only have a direct positive impact on participants, but also create positive ripple effects within the community. This is especially important in countries like Malawi, where costly initiatives such as input subsidy programs strain the economy. By prioritizing sustained adoption of SAPs, we can achieve a more cost-effective approach to agricultural interventions. Moreover, it is essential to incorporate practical, hands-on experiences in the design and scalability of climate resilient programs. By providing on-field demonstrations and training, we can empower farmers to successfully implement these technologies in their own fields, and also share their knowledge with their fellow farmers in the community. This approach not only proves to be cost-effective in the long run, but also has a greater impact on household food security.

CRediT authorship contribution statement

Wisdom Richard Mgomezulu: Writing – review & editing, Writing – original draft, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Abdi-Khalil Edriss:** Supervision, Resources, Project administration, Funding acquisition. **Kennedy Machira:** Supervision, Project administration, Investigation, Funding acquisition. **Innocent Pangapanga-Phiri:** Writing – original draft, Visualization, Validation, Supervision, Resources. **Moses Chitete:** Writing – review & editing, Methodology, Investigation, Formal analysis, Data curation.

Mwayi Mambosasa: Writing – review & editing, Methodology, Investigation, Formal analysis, Data curation. **George Chidimbah Munthali:** Writing – review & editing, Validation. **Frank Mnthambala:** Writing – review & editing, Validation.

Declaration of competing interest

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

Data availability

Data will be made available on request.

Acknowledgements

The Lilongwe University of Agriculture and Natural Resources in collaboration with the Norwegian School of Life Sciences (NMBU) through the Sustainable Food Systems in Malawi Project. Special thanks to the Agriculture Policy Analysis (APA) unit for the technical support.

References

[1] Welt Hunger Hilfe, Malawi global hunger index report. https://www.globalhungerindex.org/pdf/en/2022/Malawi.pdf, 2022.
[2] IPCC, Climate Change 2022: Impacts, Adaptation, and Vulnerability, AR 6; IPCC Sixth Assessment Report, 2022. https://www.ipcc.ch/report/ar6/wg2/downloads/report/IPCC_AR6_WGII_FinalDraft_FullReport.pdf.
[3] T. Kheira, Climate Change and Violent Conflict in West Africa: Assessing The Evidence (No. 2022/3; SIPRI Insights on Peace and Security), 2022.
[4] GoM, Report On the Monitoring of the 2020/21 Affordable Input Program. Anti-corruption Bureau, 2021.
[5] MVAC, The Malawi vulnerability assessment committee (MVAC) and integrated food security phase classification (IPC) projection updat, in: Malawi Vulnerability Assessment Committee, 2020. https://ww.ipcinfo.org/fileadmin/user_upload/ipcinfo/docs/MVAC_IPC_Malawi_AcuteFoodSec_2019Nov2020March_UpdateProjection.pdf.
[6] World Bank, Climate Smart Agriculture in Malawi, The World Bank Group, 2020.
[7] I. Pangapanga-Phiri, E.D. Mungatana, Adoption of climate-smart agricultural practices and their influence on the technical efficiency of maize production under extreme weather events, Int. J. Disaster Risk Reduc. 61 (1) (2021), https://doi.org/10.1016/j.ijdrr.2021.102322.
[8] A. Mujeyi, M. Mudhara, Economic Analysis of Climate-Smart Agriculture Technologies in Maize Production in Smallholder Farming Systems, Springer, Cham, 2021, https://doi.org/10.1007/978-3-030-45106-6_17.
[9] B. Ekman, Is it Smart to Be Climate-Smart? the Efficiency of Climate-Smart Agriculture in Tanzania [Lund University, School of Economics and Management], 2021. https://lup.lub.lu.se/luur/download?func=downloadFile&recordOId=9055012&fileOId=9055016.
[10] Z. Adimassu, S. Langan, R. Johnston, W. Mekuria, T. Amede, Impacts of soil and water conservation practices on crop yield, run-off, soil loss and nutrient loss in Ethiopia: review and synthesis, Environ. Manag. 13 (1) (2017) 87–101.
[11] N. McCarthy, T. Kilic, J. Brubaker, S. Murray, A. de la Fuente, Droughts and floods in Malawi: impacts on crop production and the performance of sustainable land management practices under weather extremes, Environ. Dev. Econ. (2021) 432–449.
[12] W.R. Mgomezulu, K. Machira, A.K. Edriss, I. Pangapanga-Phiri, Modelling farmers' adoption decisions of sustainable agricultural practices under varying agro-ecological conditions: a new perspective, Innov. Green Dev. 2 (1) (2023), https://doi.org/10.1016/j.igd.2023.100036.
[13] M.T. Ruel, A.R. Quisumbing, M. Balagamwala, Nutrition-sensitive agriculture: what have we learned so far? Global Food Secur. 17 (1) (2018) 128–153.
[14] A. Dillon, L. Bliznashka, D. Olney, Experimental evidence on post-program effects and spillovers from an agriculture-nutrition program, Econ. Hum. Biol. (2019) 100–120.
[15] A. De Brauw, M. Moursi, A.B. Munhaua, Vitamin A intakes remain higher among intervention participants 3 years after a biofortification intervention in Mozambique, Br. J. Nutr. 122 (10) (2019) 1175–1181.
[16] F.O. Amadu, P.E. McNamara, D.C. Miller, Understanding the adoption of climate smart agriculture: a farm-level typology with empirical evidence from southern Malawi, World Dev. (2020) 104–126.
[17] World Bank, The global historical weather and climate data, in: Weather and Climate, The World Bank, 2022.
[18] M. Kassie, H. Teklewold, M. Jaleta, O. Erenstein, Understanding the adoption of a portfolio of sustainable intensification practices in eastern and southern Africa 42 (1) (2015) 204–231.
[19] J. Wooldridge, Introductory Econometrics: A Modern Approach, Michigan State University, 2015.
[20] J. Krause, D.P. Croft, R. James, Social network theory in the behavioural sciences: potential applications, Behav. Ecol. Sociobiol. 62 (1) (2007) 15–27.
[21] J.C. Mitchell, Social networks, Annu. Rev. Anthropol. 3 (1) (1974) 279–299.
[22] W. Liu, A. Sidhu, A.M. Beacom, T.W. Valente, Social network theory in practice, Int. Encycloped. Media Effect. (2017).
[23] M. Gartner, Endogenous bandwagon and underdog effects in a rational choice model, Springer 25 (1) (1976) 83–89.
[24] A. Gavious, S. Mizrahi, A continous time model of the bandwagon effect in collective action, Soc. Choice Welfare 18 (1) (2001) 91–105.
[25] E.M. Rodgers, Diffusion of Innovations, third ed., The Free Press, 1983.
[26] C. Kubitza, V.V. Krishna, Instrumental variables and the claim of causality: evidence from impact studies in maize systems, Global Food Secur. 26 (1) (2020) 100–113.
[27] C. Li, D.S. Poskitt, X. Zhao, The bivariate probit model, maximum likelihood estimation, pseudo true parameters and partial identification, J. Econom. 209 (1) (2019) 94–113.
[28] NSO, Malawi Fifth Integrated Household Survey (IHS 5) 2019-2020, National Statistical Office, 2020.
[29] F.N. Bachewe, B. Koru, A.S. Taffesse, Productivity and Efficiency of Smallholder Teff Farmers in Ethiopia, 2019 [Working Paper]. file:///C:/Users/owner/Downloads/gatesopenres-183192.pdf.
[30] M. Mukhtar, Food insecurity and coping strategies among rural households in Niger state, Nigeria, Lapai J. Econ. (2019) 92–107.
[31] S. Dessy, F. Marchetta, R. Pongou, L. Tibert, Climate shocks and teenage fertility, in: Econstor. GLO Discussion Paper, Essen, 2020.
[32] W.H. Greene, Econometric Analysis, seventh ed., Prentice Hall, 2012.
[33] J. Aramburu, L.F. Garone, A. Maffioli, L. Salazar, C.A. Lopez, Direct and Spillover Effects of Agricultural Technology Adoption Programs: Experimental Evidence from the Dominican Republic (IDB Working Paper Series, No. IDB-WP-971), Inter-American Development Bank, 2019, https://doi.org/10.18235/0001742.
[34] J. Tobin, Estimation of relationships for limited dependent variables, Econometrica 26 (1) (1958) 26–36.
[35] H. Teklewold, M. Kassie, B. Shiferaw, Adoption of multiple sustainable agricultural practices in rural Ethiopia, J. Agric. Econ. 64 (3) (2013) 597–623.
[36] N.L. Atanga, A.C. Treydte, R. Birner, Assessing the sustainability of different small-scale livestock production systems in the Afar Region, Ethiopia, Land 2 (4) (2013) 726–755.
[37] I.E. Adesida, W. Nkomoki, M. Bavorova, M.Y. Madaki, Effects of agricultural programmes and land ownership on the adoption of sustainable agricultural practices in Nigeria, Sustainability 13 (13) (2021) 7249.
[38] J. Manda, A.D. Alene, C. Gardebroek, M. Kassie, G. Tembo, Adoption and impacts of sustainable agricultural practices on maize yields and incomes: evidence from rural Zambia, J. Agric. Econ. 67 (1) (2016) 130–153.
[39] M. Suvedi, R. Ghimire, M. Kaplowitz, Farmers' participation in extension programs and technology adoption in rural Nepal: a logistic regression analysis, J. Agric. Educ. Ext. 23 (4) (2017) 351–371.
[40] K. Vaiknoras, C. Larochelle, E. Birol, D. Asare-Marfo, C. Herrington, Promoting rapid and sustained adoption of biofortified crops: what we learned from iron-biofortified bean delivery approaches in Rwanda, Food Pol. 83 (1) (2019) 271–284.
[41] M.N. Mutisya, The effect of education on household food security in two informal urban settlements in Kenya: a longitudinal analysis, Food Secur. 8 (2016) 743–756, https://doi.org/10.1007/s12571-016-0589-3.
[42] M. Bavorová, J. Banout, Factors associated with household food security in Zambia, Sustainability 11 (9) (2019).
[43] E.H. Heather, Using radio and interactive ICTs to improve food security among smallholder farmers in Sub-Saharan Africa, Telecommun. Pol. 41 (7–8) (2017) 670–684.
[44] S.Y. Zakari, Factors influencing household food security in west Africa: the case of southern Niger, Sustainability 6 (3) (2014) 1191–1202, https://doi.org/10.3390/su6031191. MDPI AG.
[45] I.W. Nyakudya, L. Stroosnijder, I. Nyagumbo, Infiltration and planting pits for improved water management and maize yield in semi-arid Zimbabwe, Agric. Water Manag. 141 (2014) 30–46.
[46] B. Mitra, P.M. Bhattacharya, A. Ghosh, K. Patra, A.K. Chowdhury, M.K. Gathala, Herbicide Options for Effective Weed Management in Zero-Till Maize, 2018.
[47] H. Wei, F. Zhang, K. Zhang, R. Qin, W. Zhang, G. Sun, J. Huang, Effects of soil mulching on staple crop yield and greenhouse gas emissions in China: a meta-analysis, Field Crops Res. 284 (2022) 108566.