SUSTAINABLE INTENSIFICATION OF MAIZE PRODUCTION IN TANZANIA: EFFECTS ON CHILD NUTRITION, FOOD SECURITY, AND THE ROLE OF INPUT SUBSIDIES

By

Jongwoo Kim

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ABSTRACT

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Degraded and infertile soil, low agricultural productivity, and food and nutrition insecurity are persistent and major challenges facing many countries in sub-Saharan Africa (SSA) up to this day. Agricultural sustainable intensification (SI) has been proposed as a possible solution to simultaneously address these challenges. Yet, there is little empirical evidence on whether SI indeed improves households' incomes, nutrition, and food security. The three essays in this dissertation take various quasi-experimental approaches to investigate child nutrition and household food security effects of SI and examine the role of input subsidies in promoting SI using nationally-representative household panel survey data from Tanzania. In the empirical analysis, I focus on three important soil fertility management (SFM) practices in Tanzanian maize-based production systems: the use of inorganic fertilizer, the use of organic fertilizer, and maize-legume intercropping. I group the eight possible combinations of these technologies into four SI categories: i) "Non-adoption" (use of none of the practices), ii) "Intensification" (use of inorganic fertilizer only), iii) "Sustainable" (use of organic fertilizer, maize-legume intercropping, or both), and iv) "SI" (joint use of inorganic fertilizer with organic fertilizer and/or maize-legume intercropping). This categorization is used in all three essays.

In essay 1, results from a multinomial endogenous treatment effects model suggest that the use of practices in the "SI" category is consistently associated with improvements in children's height-for-age z-score and weight-for-age z-score, particularly for children beyond breastfeeding age (i.e., those age 25-59 months). I also find evidence that these effects come

through both productivity and income pathways, and that the combined use of inorganic fertilizer and maize-legume intercropping is a key driver of these effects on child nutrition.

Essay 2 investigates the extent to which the use of practices in each SI category influences household net crop income (per acre and per adult equivalent) and crop productivity as well as household food access (modified household dietary diversity score (HDDS), food expenditure per adult equivalent, and food consumption score (FCS)). Results from a multinomial endogenous switching regression model suggest that relative to “Non-adoption”, use of practices in each of the other SI categories has a positive and significant effect on a household’s net crop income-related outcomes and crop productivity. Importantly, for these outcomes, the “SI” category has either larger or similar-in-magnitude effects compared to “Intensification”, and consistently larger effects than “Sustainable” practices. The results further suggest that a household’s use of packages in the “SI” category is significantly associated with increases in all three food access outcomes, with the size of these effects similar to or greater than those of “Sustainable” practices and consistently larger than the effects of “Intensification”.

Essay 3 explores whether Tanzania’s input subsidy program (ISP) from 2008 to 2014, the National Agricultural Input Voucher Scheme (NAIVS), encouraged or discouraged farmers’ use of practices in the various SI categories on their maize plots using a multinomial logit model combined with the control function approach. I find statistically significant positive effects of household receipt of a NAIVS voucher for inorganic fertilizer on maize-growing households’ use of inorganic fertilizer only (i.e., “Intensification”) and on their combined use of inorganic fertilizer with organic fertilizer and/or maize-legume intercropping (i.e., “SI”). On the other hand, no such effects are found for the “Sustainable” category.

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KEY TO ABBREVIATIONS

AMIS	Agricultural Market Information System
APE	Average partial effect
ATT	Average treatment effects on the treated
ATU	Average treatment effects on the untreated
BMI	Body mass index
CA	Conservation Agriculture
CF	Control function
CRE	Correlated random effects
FCS	Food consumption score
FE	Fixed effects
HAZ	Height-for-age z-score
HDDS	Household dietary diversity score
IIA	Independence of irrelevant alternatives
IMR	Inverse Mills ratio
ISFM	Integrated Soil Fertility Management
ISP	Input subsidy program
IV	Instrumental variable
LSMS-ISA	Living Standards Measurement Study-Integrated Surveys on Agriculture
METE	Multinomial endogenous treatment effects
MESR	Multinomial endogenous switching regression
MIT	Ministry of Industry and Trade

MNL	Multinomial logit
MNLS	Multinomial logit selection
NAIVS	National Agricultural Input Voucher Scheme
OLS	Ordinary least squares
SACCOS	Savings and Credits Cooperatives Societies
SFM	Soil fertility management
SI	Sustainable intensification
SOC	Soil organic carbon
SOM	Soil organic matter
SSA	Sub-Saharan Africa
TNBS	Tanzania National Bureau of Statistics
TNPS	Tanzania National Panel Surveys
TZS	Tanzania Shillings
WAZ	Weight-for-age z-score
WHO	World Health Organization

INTRODUCTION

Degraded and infertile soil, low agricultural productivity, and food and nutrition insecurity are persistent and major challenges facing many countries in sub-Saharan Africa (SSA) up to this day. In 2017, about 236 million people (23.2% of the population) in SSA were undernourished and approximately 40% of globally stunted children under age five (151 million children) lived in Africa (FAO, IFAD, UNICEF, WFP, and WHO, 2018). Agriculture in this region is particularly important to alleviate food and nutrition insecurity since most undernourished people reside in rural areas and many of them are small-scale farm households (Sibhatu et al., 2015). This implies that households' use of more efficient agricultural inputs or management practices could play a crucial role in addressing these challenges, including low agricultural productivity and poor soil fertility issues. For example, farmers' use of inorganic fertilizer and high-yielding crop varieties could improve the food security and nutritional status of household members by increasing agricultural productivity and/or crop income, as well as by enhancing farmers' ability to access diverse and nutritious foods (Jones et al., 2014). However, there is an emerging consensus that the sole use of these practices, or conventional intensification of agricultural systems, may not be sufficient to *sustainably* intensify agricultural production and thus it may not be a solution to achieving food and nutrition security (The Montpellier Panel, 2013; Kassie et al., 2015). Nonetheless, many African governments have still concentrated on encouraging farmers' use of conventional intensification practices through large-scale input subsidy programs (ISPs) (Jayne et al., 2018). In this context, agricultural sustainable intensification (SI) has received a great deal of attention as a possible solution to address these challenges (The Montpellier Panel, 2013; Petersen and Snapp, 2015). At the core of SI is the goal of improving not only agricultural yields but also nutrition and food security without bringing new land under cultivation, while preserving or enhancing the natural resource base (Pretty et al., 2011; Godfray et al., 2010; Loos et al., 2014). However, there is little empirical evidence on whether SI indeed improves households' incomes, nutrition, or food security.

The three essays in this dissertation take various quasi-experimental approaches to investigate child nutrition and household food security effects of SI and examine the role of input subsidies in promoting SI using nationally-representative household panel survey data from Tanzania. For the empirical analysis, I focus on three important soil fertility management (SFM) practices in Tanzanian maize-based production systems: the use of inorganic fertilizer, the use of organic fertilizer, and maize-legume intercropping. Given eight possible combinations of these technologies, I group them into four SI categories: i) "Non-adoption" (use of none of the practices), ii) "Intensification" (use of inorganic fertilizer only), iii) "Sustainable" (use of organic fertilizer, maize-legume intercropping, or both), and iv) "SI" (joint use of inorganic fertilizer with organic fertilizer and/or maize-legume intercropping). This categorization is used in all three essays. Results from this dissertation will help policymakers understand potential impacts of each SI category on nutrition and food security as well as design agricultural policies for promoting SI in maize-based systems.

The first essay (Chapter 1) analyzes how household's use of practices in each SI category affects the nutritional status (height-for-age z-score (HAZ) and weight-for-age z-score (WAZ)) of household members under age five using a multinomial endogenous treatment effects model. Results suggest that, compared to households that use none of the practices, households' use of practices in the "SI" category is consistently associated with improvements in their children's HAZ and WAZ, particularly for children beyond breast-feeding age (i.e., those age 25-59 months). I also find evidence that these effects come through both productivity and income pathways, and that the combined use of maize-legume intercropping and inorganic fertilizer is a key driver of the effects on child nutrition. However, this essay finds no empirical evidence that “Intensification” or “Sustainable” agricultural practices improve child nutritional outcomes.

The second essay (Chapter 2) investigates the extent to which the use of practices in each SI category influences household net crop income-related variables (net crop income, net crop income per acre, and net crop income per adult equivalent) and crop productivity. Furthermore, I examine whether the use of these practices indeed improves households’ food access (modified household dietary diversity score (HDDS), food expenditure per adult equivalent, and food consumption score (FCS)). Results in a multinomial endogenous switching regression model suggest that relative to “Non-adoption”, the use of practices included in each SI category (i.e., “Intensification”, “Sustainable”, and “SI”) has a positive and significant effect on household net crop income-related outcomes and crop productivity. For these outcomes, use of practices in the “SI” group has either larger or similarly-sized effects to “Intensification” and consistently larger effects than “Sustainable” practices. I also find that use of “SI” practices is significantly associated with increases in all three food access outcomes. These effects are consistently larger than the “Intensification” effects and either larger or similar in magnitude to the effects of “Sustainable” practices. Together, these results suggest that improvements in household food access associated with the use of “SI” practices are coming through both crop productivity and income pathways. The results also shed light on the findings in Essay 1 and suggest that the positive effects of “SI” practices on child nutrition outcomes may be driven by improvements in both the quantity and diversity of food items consumed (including legumes produced via maize-legume intercropping).

The third essay (Chapter 3) explores whether Tanzania's ISP from 2008 to 2014, the National Agricultural Input Voucher Scheme (NAIVS), encourages or discourages farmers' use of individual SFM practices and/or a combination thereof on their maize plots. Understanding how ISPs affect farmers' use of complementary SFM practices leads to important policy implications as it relates to agricultural productivity, food security, poverty, long-run soil health, and the returns to government spending on ISPs. Using a multinomial logit model combined with the control function approach, I find statistically significant positive effects of household receipt of a NAIVS voucher for inorganic fertilizer on maize-growing farmers' use of inorganic fertilizer only (i.e., "Intensification"): the probability of using inorganic fertilizer only is on average 10.0 percentage points higher than for households who do not receive a NAIVS fertilizer voucher. Results further suggest that NAIVS voucher receipt encourages farmers to adopt multiple SFM practices that could contribute to SI. More specifically, NAIVS voucher receipt for inorganic fertilizer is associated with a 9.6 percentage point increase in the probability of using practices in the "SI" group. On the other hand, no such effects are found for the practices in "Sustainable" group. I also find that receipt of a NAIVS voucher for maize seed has no statistically significant effect on farmers' SI category decisions. The positive effects of NAIVS on joint use of inorganic fertilizer with organic SFM practices is encouraging, as it suggests that the program may have helped promote not just short-run increases in maize yields but also longer-term improvements in soil health.

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CHAPTER 1

DOES SUSTAINABLE INTENSIFICATION OF MAIZE PRODUCTION ENHANCE CHILD NUTRITION? EVIDENCE FROM RURAL TANZNIA

This essay has been accepted for publication in *Agricultural Economic* with Jongwoo Kim as the lead and corresponding author. The citation is as follows:

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1.1 Introduction

Food insecurity and malnutrition continue to be urgent global problems. Although increases in agricultural productivity have dramatically improved food and nutrition security in many parts of the world over the past five decades, approximately 795 million people worldwide remain undernourished and most of them live in developing countries (Godfray et al., 2010; FAO, 2015; Koppmair et al., 2016). Hunger and child malnutrition are especially serious problems in sub-Saharan Africa (SSA). For example, in 2017, globally about 151 million children under age five were stunted and more than one third of these children lived in Africa (UNICEF, WHO, and World Bank Group, 2018). Moreover, approximately 45% of global deaths of children under age five are linked to malnutrition and the mortality rate of children in SSA is the highest in the world (Black et al., 2013).

Agriculture and nutrition are closely linked because the majority of undernourished people live in rural areas and many of them are smallholder farmers (Sibhatu et al., 2015; Pinstrup-Andersen, 2007). This linkage suggests that agricultural intensification via farmers' adoption of improved inputs and management practices may improve the nutritional status of nutritionally vulnerable household members including young children by enhancing the household's agricultural production, productivity, and/or income, as well as by providing better access to more diverse or nutritious foods (Jones et al., 2014; Hawkes and Ruel, 2006). However, there is an emerging consensus that conventional agricultural intensification via high-yielding crop varieties and inorganic fertilizer may be insufficient to sustainably raise agricultural productivity and could have negative environmental consequences (Pingali, 2012; Montpellier Panel, 2013). Moreover, in many parts of SSA, rapidly growing populations and a lack of new land to farm has led to continuous cultivation of plots and reduced fallowing, thereby degrading soils and adversely affecting crop yields and yield response to inorganic fertilizer (Kassie et al., 2013; Tully et al., 2015; Jayne et al., 2018).

Agricultural sustainable intensification (SI) has been proposed as a possible solution to address these challenges (Montpellier Panel, 2013; Petersen and Snapp, 2015). At the core of SI is the goal of "producing more food from the same area of land while reducing the environmental impacts" (Godfray et al., 2010, p. 813). Broader definitions of SI also encompass the complex social dimensions of sustainability, including nutrition and food security (Loos et al., 2014; Musumba et al., 2017). It is an open question, however, whether the use of agricultural inputs and management practices that contribute to SI from an environmental standpoint do indeed improve nutrition and food security. In this study, we contribute to the thin evidence base on this topic by estimating the effects of SI of maize production on the child nutrition outcomes of maize-growing households in Tanzania. We focus on maize due to its importance as a staple food in Tanzania and because it accounts for approximately 75% of total cropped area in the country (Tanzania National Bureau of Statistics (TNBS), 2014).

To our knowledge, only two previous studies have examined the relationship between SI of maize production and child nutrition (Manda et al. (2016a) and Zeng et al. (2017)), and both focus on adoption of improved maize varieties. Yet there are numerous other agricultural practices that can contribute to the SI of maize production and potentially affect child nutrition. In this study, we extend the existing literature and focus on three soil fertility management (SFM) practices: the use of inorganic fertilizer, the use of organic fertilizer, and maize-legume intercropping. We group households into four "SI categories" based on their use of these practices on their maize plots: "Non-adoption" (use of none of the practices); "Intensification" (use of inorganic fertilizer only); "Sustainable" (use of organic fertilizer, maize-legume intercropping, or both); and "SI" (joint use of inorganic fertilizer with organic fertilizer and/or maize-legume intercropping, which is a form of integrated soil fertility management (ISFM; Place et al., 2003)). Using nationally representative household panel survey data from Tanzania, we then estimate how the adoption of these SI categories by maize-growing households affects the nutrition outcomes (height-for-age z-score (HAZ) and weight-for-age z-score (WAZ)) of household members under age five.[1]

This study further contributes to the literature in several ways. First, to our knowledge, it is the first empirical investigation of how *combinations* of agricultural practices in general (as opposed to single technologies) and ISFM in particular affect child nutrition. Second, we explore whether these effects operate through the crop productivity and/or income pathways. Third, we use household-level panel data, whereas Manda et al. (2016a) and Zeng et al. (2017) use cross-sectional data. This enables us to control for time-constant unobserved heterogeneity, which should improve the internal validity of our estimates. And fourth, we contribute to the production diversity-dietary diversity/nutrition literature (see, for example, Jones et al., 2014; Kumar et al.,

[1] Several recent studies in *Agricultural Economics* have examined the determinants of adoption (and/or impacts on outcomes other than child nutrition) of some of these practices or other land management practices in SSA (e.g., Wossen et al., 2015; Abdulai, 2016; Manda et al., 2016b; Wainaina et al., 2016; Amare and Shiferaw, 2017; and Schmidt et al., 2017).

2015; Sibhatu et al., 2015; Hirvonen and Hoddinott, 2017; Parvathi, 2018) by studying whether production diversity (proxied in this study by maize-legume intercropping), intensification (proxied by inorganic fertilizer use on maize), or a combination of the two is most beneficial for child nutrition outcomes.[2]

Our results suggest that, compared to the base category of “Non-adoption”, adoption of the “SI” treatment group is consistently associated with improvements in children’s HAZ and WAZ, particularly for children beyond breast-feeding age (i.e., those age 25-59 months). We find evidence that these effects come through both the productivity and income pathways, and that the combined use of maize-legume intercropping and inorganic fertilizer is a key driver of the effects on child nutrition.

1.2 Sustainable intensification of maize production in Tanzania

This study focuses on Tanzanian farm households’ use of inorganic fertilizer, organic fertilizer, and maize-legume intercropping on their maize plots. As mentioned above, we define use of inorganic fertilizer alone as “Intensification”; use of organic fertilizer only, maize-legume intercropping only, or both as “Sustainable”; and joint use of inorganic fertilizer with organic fertilizer, maize-legume intercropping, or both as “SI”. The rationale is as follows.

Inorganic fertilizer is a key input associated with conventional agricultural intensification and it has been a major reason for the dramatic increase in food production globally over the past 50 years (Crews and Peoples, 2005; Pingali, 2012). However, overuse of inorganic fertilizer can result in pollution of ground and surface water (Byrnes, 1990; Hart et al., 2004), and chemical fertilizer application without the use of complementary soil building practices (e.g., maize-

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[2] We thank an anonymous reviewer for highlighting this.

legume intercropping and organic fertilizer) may lead to a decrease in soil pH, soil organic carbon, soil aggregation, and microbial communities (Bronick and Lal, 2005).

Maize-legume intercropping and the use of organic fertilizer in the form of manure or compost are widely recognized as “Sustainable” agricultural practices by agronomists and soil scientists (Ollenburger and Snapp, 2014; Droppelmann et al., 2017; Mpeketula and Snapp, 2018).[3] Organic fertilizer can be produced in a renewable manner, locally, and can enhance soil structure and water retention capacity, encourage the growth of beneficial micro-organisms and earthworms, and decrease bulk density (Chen, 2006; Bronick and Lal, 2005). However, there are often limitation in terms of locally sourcing large quantities, it has a long-time horizon for observed benefits, and it is often not sufficient to substantially raise productivity.

Maize-legume intercropping is another local and renewable source of soil fertility. Moreover, compared to continuous sole-cropped maize, it can improve soil properties for nutrient and moisture-holding capacity, and reduce weeds, pests, and diseases (Snapp et al., 2010; Tilman et al., 2002; Woodfine, 2009). Legumes can also benefit household nutrition, providing needed protein and micronutrients such as iron, zinc, or vitamin A (Messina, 1999). Because of these benefits, some authors consider maize-legume intercropping to be an SI practice (Rusinamhodzi et al., 2012). However, maize yields in certain contexts may be negatively affected by intercropping (Agboola and Fayemi, 1971; Waddington et al., 2007), and intercrop systems generally require complementary investments in order to support high crop yields. For these reasons, we categorize organic fertilizer and maize-legume intercropping as “Sustainable” practices but not sufficient to sustainably intensify maize production without joint use with inorganic fertilizer.

[3] We recognize that this designation may not be universally accepted.

Table 1.1 shows the prevalence of each of the eight possible combinations of the three SFM practices and each of the four SI categories on Tanzanian households' maize plots. Out of 6,383 maize plots pooled across three rounds of survey data (the Tanzania National Panel Surveys (TNPS) of 2008/09, 2010/11, and 2012/13, described below), 38% fall in the "Sustainable" category, 7% in "Intensification", 8% in "SI", and 47% in "Non-adoption". For the empirical approach used in this study and described below (a multinomial endogenous treatment effects (METE) model), we need to define a household-level SI category variable based on the plot-level SI category information. (This is because the METE model requires that the 'treatment' variable be a mutually exclusive categorical variable.) To do so, we calculate the total area of a household's maize plots in each SI category and then choose the SI category that has the largest area. The prevalence of these household-level SI categories is summarized in Table 1.1 and is very similar to the plot-level results. This is because 64% of households in the sample have only one maize plot, and those with multiple maize plots tend to use the same SFM practices on all maize plots. Overall, 87% of the maize plots in the sample have the same SI category at the plot- and household-level.[4]

[4] There is considerable variation in a household's SI category over time, which is important for the panel data methods used here. Of sample households that appear in only two survey rounds, 43% changed categories between rounds; of sample households in all three rounds, 56% changed categories at least once.

Table 1.1: SI of maize production categories and prevalence on maize plots and among maize-growing households in Tanzania

Case	Inorganic fertilizer	Organic fertilizer	Maize-legume intercropping	% of maize plots	SI category	% Plot level	% HH level
1				46.5	Non-adoption	46.5	44.3
2	√			7.3	Intensification	7.3	6.1
3		√		6.3			
4			√	26.8	Sustainable	38.1	40.8
5		√	√	5.0			
6	√	√		1.7			
7	√		√	5.2	SI	8.1	8.8
8	√	√	√	1.2			
Use of inorganic fertilizer						15.4	16.1
Use of organic fertilizer						14.2	18.1
Use of maize-legume intercropping						38.2	46.6

Notes: Figures in the plot level column are based on all maize plots (N=6,383) cultivated by rural households pooled across the three waves of the TNPS (2008/09, 2010/11, and 2012/13). Figures in the HH level column are based on the total number of maize growers (N=4,269) in rural areas across these surveys. Legume crops for maize-legume intercropping are beans, soybeans, groundnuts, cowpeas, pigeon peas, chickpeas, field peas, green grams, bambara nuts, and fiwi.

1.3 Conceptual and econometric framework

1.3.1 Conceptual framework

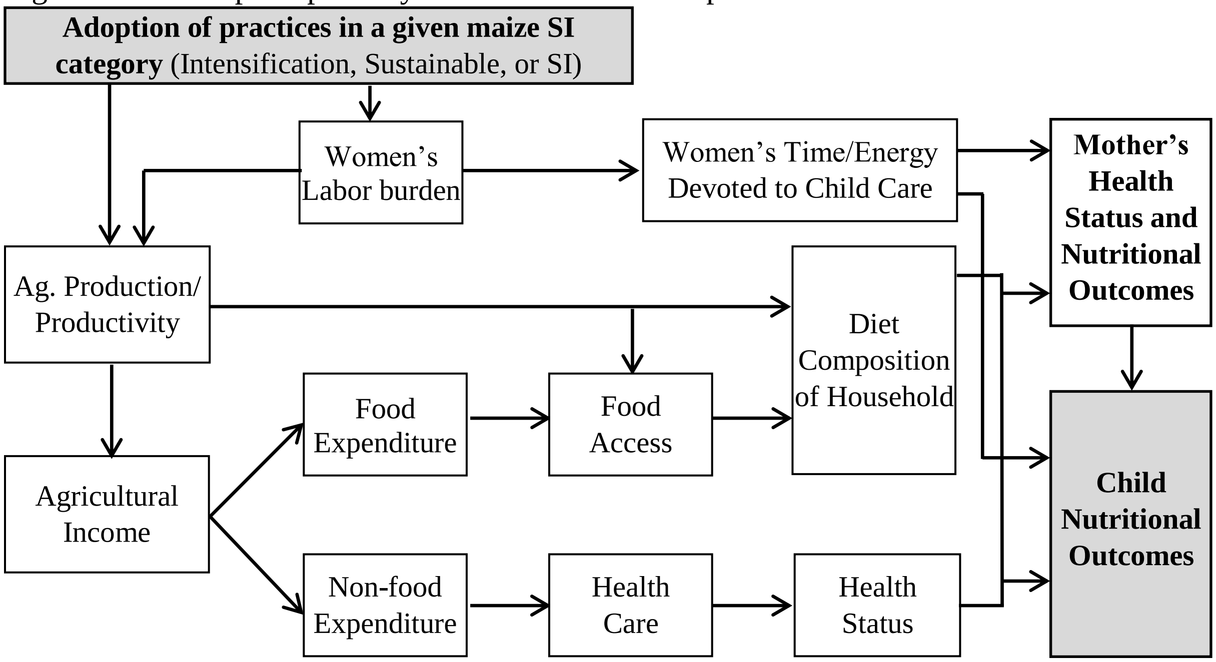
Tanzania is the third worst affected country in SSA based on the prevalence of stunting (UNICEF, 2009). As of 2012/13, 37.4% of children under age five were stunted (i.e., HAZ < -2) and 12.5% were underweight (i.e., WAZ < -2), with the prevalence of malnutrition markedly higher in rural than in urban areas (TNBS, 2014).[5] HAZ and WAZ reflect long-term factors such

[5] HAZ and WAZ measure nutritional status in the form of z-scores derived by comparing a child's height-for-age and weight-for-age, respectively, with that of a reference population of well-nourished children. The World Health Organization (WHO) Child Growth Standards and WHO Reference 2007 composite data files are used as the reference data. See Heady et al. (2018) for an analysis of differences in child nutrition between rural and urban areas throughout SSA.

as deficiencies in nutrition, frequent infections, and inappropriate feeding practices (Alderman et al., 2006; TNBS, 2014).

Recent studies suggest that agricultural interventions or technologies can affect child nutrition through two main pathways: (1) food production/productivity; and (2) agricultural income (Herforth and Harris, 2014; Kumar et al., 2015). Figure 1.1 depicts these pathways in the context of this study. First, relative to "Non-adoption", adoption of practices in the other SI categories may directly increase production and/or productivity of maize, a key food staple. Adopting maize-legume intercropping (via the "Sustainable" and "SI" categories) could directly affect households' diet composition by providing leguminous crops with a range of essential nutrients. More diverse and larger quantities of produced foods could also mean less needs to be purchased to meet households' consumption needs, thereby freeing up cash to purchase other items. Practices in the "Intensification", "Sustainable", or "SI" categories may also increase households' crop income through generating larger marketable surpluses of maize and/or legume crops, which, in turn, could raise expenditures on high calorie and protein-rich foods as well as non-food expenditures on health services, sanitation, and access to clean water. Adoption of the various SFM practices may also affect women's labor burden and time allocation, which could affect child nutrition outcomes directly or indirectly through effects on the mother's health and nutrition. As described below, we estimate the effects of a household's adoption of the various SI categories on: (i) the HAZ and WAZ of children under age five in the household, and (ii) crop income from and productivity on their maize plots. The purpose of (ii) is to explore the pathways through which (i) occurs.

Figure 1.1: Conceptual pathways between SI of maize production and child nutrition.



Source: Adapted from Herforth and Harris (2014).

1.3.2 Multinomial endogenous treatment effects model

Because farmers often self-select into agricultural technology adopter groups or some technologies are targeted to certain groups of farmers, selection bias and endogeneity may arise (Manda et al., 2016a; Kassie et al., 2015b). In the context of this paper, these problems occur if unobserved factors affecting a household's SI category adoption decision are correlated with children's HAZ and WAZ. For example, suppose the head of household is highly motivated and curious, and as a result of these traits, actively seeks out information not only on the benefits of various SFM practices but also on how to improve his/her children's nutrition. If omitted, the household head's motivation could make it appear that the adoption of certain SI categories is associated with child nutrition outcomes even if there is no causal relationship.

To address these concerns, we use an METE model (Deb and Trivedi, 2006a, b) because it allows us to evaluate alternative combinations of practices (SI categories) and corrects for both self-selection and the potential interdependence of adoption decisions over SFM practices (Wu and Babcock, 1998; Manda et al., 2016b). We combine the METE model with Mundlak-Chamberlain correlated random effects (CRE) techniques to further control for time-invariant unobserved household-level heterogeneity that may be correlated with observed covariates (e.g., motivation in the example above), where the household means of time-varying household-level explanatory variables are included as additional regressors (Wooldridge, 2010). As a benchmark to the CRE-METE models, we also report household fixed effects (FE) and CRE-pooled ordinary least squares (POLS) results for the main model below.[6]

The METE model involves two stages. In the first stage, household *i* chooses one of the four SI categories. Following Deb and Trivedi (2006a, b), let EV_{ij}^* denote the indirect utility obtained by household *i* from selecting the *j*th SI category, $j = 0, 1, 2, 3$:

$$EV_{ij}^* = \boldsymbol{z}_i'\boldsymbol{\alpha}_j + \delta_j l_{ij} + \eta_{ij} \tag{1}$$

Without loss of generality, let *j*=0 denote the control group ("Non-adoption") and $EV_{ij}^* = 0$. $\boldsymbol{z}_i$ is a vector of exogenous covariates (described below) with associated parameters $\boldsymbol{\alpha}_j$; η_{ij} are independently and identically distributed error terms; and l_{ij} is unobserved characteristics common to household *i*'s adoption of the *j*th alternative and the outcome variables (HAZ and WAZ).

EV_{ij}^* is not directly observed but we do observe a vector of binary variables, $\boldsymbol{d}_i = (d_{i1}, d_{i2}, d_{i3})$, representing whether a household adopted a given SI category. The probability of treatment can be expressed as:

[6] Note that if all explanatory variables are time-varying, FE and POLS-CRE are algebraically equivalent in linear models. However, several household-level regressors in our models are time-invariant for almost all households (e.g., education of the household head, distance to the nearest market, and a binary variable for livestock ownership); per guidance from J. Wooldridge (personal communication, 2017), we exclude the time averages of these variables from models that use CRE.

$$\Pr\left(d_{ij} = 1 \middle| \boldsymbol{z}_i, l_{ij}\right) = g\left(\boldsymbol{z}_i'\boldsymbol{\alpha}_j + \delta_j l_{ij}\right), \qquad j = 1, 2, 3. \tag{2}$$

Following Deb and Trivedi (2006a), we assume that g has a mixed multinomial logit structure, i.e.:

$$\Pr\left(d_{ij} = 1 \middle| \boldsymbol{z}_i, l_{ij}\right) = \frac{\exp(\boldsymbol{z}_i'\boldsymbol{\alpha}_j + \delta_j l_{ij})}{1 + \sum_{k=1}^{3} \exp(\boldsymbol{z}_i'\boldsymbol{\alpha}_k + \delta_k l_{ik})} \tag{3}$$

In the second stage, we estimate the impact of the adoption of the various SI categories on HAZ and WAZ using OLS with a selectivity correction term from the first stage.[7] The expected outcome equation is written as:

$$E\left(y_{i,n} \middle| \boldsymbol{d}_i, \boldsymbol{x}_i, \boldsymbol{l}_i\right) = \boldsymbol{x}_i'\boldsymbol{\beta} + \sum_{j=1}^{3} \gamma_j d_{ij} + \sum_{j=1}^{3} \lambda_j l_{ij}, \tag{4}$$

where $y_{i,n}$ is the nutrition outcome of interest for child *n* in household *i*. $\boldsymbol{x}_i$ is a vector of exogenous covariates including two sub-vectors: household *i*'s characteristics $\boldsymbol{h}_i$ and child *n*'s characteristics $\boldsymbol{c}_{i,n}$. The associated parameter vector is $\boldsymbol{\beta}$. Parameters γ_j (for $j = 1, 2, 3$) denote the treatment effects relative to the control group ("Non-adoption"). $E\left(y_{i,n} \middle| \boldsymbol{d}_i, \boldsymbol{x}_i, \boldsymbol{l}_i\right)$ is a function of each of the latent factors l_{ij}; that is, the outcome variable may be influenced by unobserved characteristics that also affect selection into treatment. If λ_j is positive (negative), treatment and outcome are positively (negatively) associated with unobserved variables – i.e., there is positive (negative) selection. We assume that the outcome variables (z-scores) follow a normal distribution. The model is estimated using a maximum simulated likelihood approach and 700 Halton sequence-based quasi-random draws.[8]

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[7] We also wanted to estimate models for the probability of being stunted and underweight but these models do not converge.

[8] 500 Halton sequence-based quasi-random draws are used for the WAZ models in the full-sample analyses in Table A5 because the models do not converge when 700 are used.

In principle, the parameters of the semi-structural model are identified through nonlinear functional forms; however, including some variables in $\boldsymbol{z}_i$ that do not enter in $\boldsymbol{x}_i$ is the preferred approach for more robust identification (Deb and Trivedi, 2006a, b). We therefore include the following as excluded instrumental variables (IVs): the proportion of *other* households in the household's ward (excluding the household itself) that (i) received agricultural production advice, (ii) that used inorganic fertilizer, and (iii) that used maize-legume intercropping; (iv) electoral threat at the district level; and (v) the number of National Agricultural Input Voucher Scheme (NAIVS) subsidized fertilizer vouchers allocated to the household's region.[9] The first three IVs are related to access to information on and the potential for social learning about SFM practices.[10] We expect these variables to be positively correlated with household *i*'s adoption of SFM practices but not to directly affect the household's child nutrition outcomes. Regarding IVs (iv) and (v), a household's SI category decision could be affected by its receipt of subsidized fertilizer vouchers; however, this is likely to be endogenous, so we instead use (iv) and (v) because these are likely to affect the household's receipt of such vouchers but are exogenous to an individual household. Electoral threat, as defined by Chang (2005), is the proportion of votes for the runner-up divided by the proportion of votes for the presidential winner. Previous studies indicate that the spatial allocation of subsidized inputs in some SSA countries, including Tanzania, may be linked to voting patterns during the most recent election (see, among others, Mason et al. (2017) for Zambia; Mather and Minde (2016) for Tanzania; and Mather and Jayne (2018) for Kenya). We therefore use Mather and Minde's electoral threat variable, which is

[9] We also considered the proportion of other households that used organic fertilizer but it did not pass the falsification test described below.

[10] Similar variables have been used as selection instruments by Di Falco et al. (2011), Di Falco and Veronesi (2013), and Manda et al. (2016a, b).

based on data from the 2005 and 2010 Tanzania presidential elections.[11] Subsidized fertilizer vouchers for maize in Tanzania are also targeted based on the suitability of different areas for maize production.[12] We therefore include as another IV the number of vouchers allocated to the household's region per the World Bank (2014).

Although there is no formal test for the validity of exclusion restrictions in a nonlinear setting (Deb and Trivedi, 2006a), we follow Di Falco et al. (2011) and perform a simple falsification test where these candidate IVs are included as additional explanatory variables along with $\boldsymbol{z}_i$ in a CRE-POLS regression, while the dependent variable is the HAZ or WAZ of children in households in the "Non-adoption" group. If the candidate IVs are not statistically significant in this regression, this lends support to the validity of the exclusion restrictions. All IVs used here pass this simple falsification test (see Table 1A.1 in the appendix); however, we acknowledge that this is not ironclad evidence that the exclusion restrictions are valid. A useful extension of this study would be a randomized-controlled trial that generates exogenous variation in the adoption of the SI categories (e.g., through different information treatments) and measures the effects on child nutrition.

1.4 Data

With the exception of IVs (iv) and (v) above, the data come from the TNPS, which is a nationally-representative household survey that contains detailed information on socioeconomic characteristics, consumption, agricultural production, and non-farm income generating activities, *inter alia*. The TNPS is a four-wave panel survey conducted in 2008/09, 2010/11, 2012/13, and

[11] The authors thank Dr. David Mather for sharing these data.
[12] Recall that we are controlling for time invariant heterogeneity, including suitability for maize production, via CRE.

2014/15 but only the data from the first three waves are used here because the sample in the fourth wave was refreshed for future rounds. The TNPS is based on a stratified, multi-stage cluster sample design and the clusters within each stratum are randomly selected as the primary sampling units, where there are four different strata: Dar es Salaam, other urban areas on mainland Tanzania, rural mainland Tanzania, and Zanzibar. The TNPS baseline (2008/09) sample of 3,265 households is clustered in 409 enumeration areas. These households and their members were tracked and re-interviewed in the second (TNPS 2010/11) and third waves (TNPS 2012/13) with very low attrition rates between waves (TNBS, 2014).

We start with observations of children under age five (0-59 months) in rural households that grew maize in the main farming season (i.e., the long-rainy season) in a given wave but drop children age 0-5 months because they are typically exclusively breastfed during that period (Tanzania Food and Nutrition Centre, 2014) and thus less likely to be directly affected by diet changes associated with their household's SI adoption decisions. There are 1,871 total household observations meeting these criteria across the three waves of the TNPS (532 observations in 2008/09, 560 in 2010/11, and 779 in 2012/13). These households contain a total of 2,486 children age 6-59 months (693 observations in 2008/09, 727 in 2010/11, and 1,066 in 2012/13).

Per Table 1A.2 in the appendix, among children in our sample, the mean values of HAZ and WAZ are -1.82 and -0.98, respectively; 47% are stunted and 15% are underweight. (This table and Table 1A.3 also show descriptive statistics by SI category.) Anthropometric data to calculate nutritional status were collected from children an average (and median) of 10 months after the household began harvesting the maize (and this timing is controlled for in the econometric models). This implies that most children's WAZ and HAZ in our sample are mainly influenced by the household's SFM adoption decisions captured in the data and not by such decisions in the following year.

Tables 1A.2 and 1A.3 in the appendix further provide summary statistics for the control variables used in the analysis. These variables were selected based on careful reviews of the technology adoption and child nutrition literatures and include child-level variables (age and gender, whether or not the child had diarrhea in the past two weeks, mother's education, monthly difference between maize harvest and collection of anthropometric data, and dummy variables for number of times the child appears across survey rounds); household characteristics (age and gender of the household head, education level of the household head and spouse, family labor (as defined in Table 1A.3), number of female adults/elderly/children/siblings in the household, marital status of the household head, off-farm income, access to a safe drinking water source, use of safe drinking water, basic sanitation (toilet)); agricultural characteristics (total cultivated land; maize plot, farm equipment, and livestock ownership; distance to the nearest market); input and output prices; and community characteristics (whether or not a government health center/hospital is available within the community).

A child's biological parents' height and weight could also affect his/her nutritional status. However, such data on the child's biological father (mother) is missing for approximately 36% (15%) of the observations in our sample because the individual is no longer a household member or was otherwise not present when measurements were taken. Many models fail to converge with these reductions in sample size; however, we do report, as a robustness check, estimates that control for the mother's body mass index (BMI) (and age).[13] An important caveat is that BMI could be affected by if the woman is pregnant or not, but the TNPS data do not capture

[13] BMI is equal to weight (in kilograms), divided by height (in meters) squared.

information on current pregnancy; thus there is likely to be measurement error in the BMI variable for at least some observations. Our inability to fully control for these biological parent characteristics is a limitation of this study. However, note that if height (of adults) is reasonably assumed to be constant over the survey waves, then our use of CRE indirectly controls for the parents' height.

1.5 Results

Table 1.2 presents the CRE-METE estimates of the local average treatment effects of the various SI categories on children's HAZ and WAZ for the full sample of children aged 6-59 months. See Tables 1A.4 and 1A.5 in the appendix for the full first- and second-stage results for this model. (Also note in Table 1A.4 that two of the IVs associated with an increased probability of adoption of practices in the SI category by a given household are increases in the proportion of *other* households in the household's ward that use inorganic fertilizer or that practice maize-legume intercropping. We return to this point in the final section of the paper on policy implications.) For comparison purposes, we also report FE and CRE-POLS results that are estimated under the assumption that a household's SI category decision is exogenous after controlling for the observed covariates and time-invariant heterogeneity. The results of both the FE and CRE-POLS models suggest that there are no statistically significant nutritional effects for any of the SI treatment groups. However, we reject the null hypothesis of joint exogeneity of the SI category variables in all CRE-METE models estimated here, which suggests that endogeneity is indeed an issue.[14] In subsequent parts of this section we therefore focus on the CRE-METE results, which correct for self-selection.

Table 1.2: FE, CRE-POLS, and CRE-METE estimates: Impacts on nutritional outcomes of children aged 6-59 months (full sample)

Variables	HAZ	WAZ
FE		
Intensification	0.069	-0.128
	(0.303)	(0.235)
Sustainable	0.043	0.030
	(0.118)	(0.098)
SI	-0.194	-0.271
	(0.291)	(0.215)
CRE-POLS		
Intensification	0.052	0.093
	(0.132)	(0.114)
Sustainable	0.039	0.020
	(0.069)	(0.055)
SI	-0.070	0.007
	(0.106)	(0.093)
CRE-METE		
Intensification	-0.463***	-0.266
	(0.176)	(0.170)
Sustainable	0.116	0.200
	(0.160)	(0.133)
SI	0.355**	0.453***
	(0.155)	(0.125)
Selection terms (λ)		
Intensification (λ_I)	0.443**	0.647***
	(0.177)	(0.125)
Sustainable (λ_S)	-0.232	-0.103
	(0.151)	(0.188)
SI (λ_{SI})	-0.592***	-0.557***
	(0.125)	(0.155)

Notes: N=2,486. Base category is "Non-adoption". ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. Standard errors clustered at the household level in parentheses.

[14] This test, following Deb and Trivedi (2006b), is a likelihood-ratio test where the null hypothesis is that the λs (selection terms) are jointly equal to zero (exogeneity of treatment). We reject the null in all cases (p< 0.01), which suggests that treatment is endogenous. To conserve space, we do not report the estimated λs in subsequent tables.

The CRE-METE results in Table 1.2 suggest that, on average, use of practices in the "SI" category is associated with increases in children's HAZ and WAZ of 0.36 units and 0.45 units, respectively, compared to those in non-adopting households. These are sizeable increases relative to the sample mean HAZ and WAZ of -1.82 and -0.98, respectively.[15] Moreover, the estimated increase in HAZ (WAZ) would lift 26% of stunted children (53% of underweight children) in our sample to the -2 cutoff. In contrast, use of inorganic fertilizer only ("Intensification") is associated with a decrease in children's HAZ of 0.46 units, and there are no statistically significant effects for the "Sustainable" category.

In addition to estimating the CRE-METE models for the full sample of children aged 6-59 months, we also estimate models for: (i) children aged 6-59 months with interaction terms between the SI treatment groups and an indicator variable for children aged 6-24 months; and (ii) children aged 25-59 months only. The major rationale behind these additional analyses is that the growth faltering patterns of children under age five differ across ages (see Figure 1A.1 in the appendix). Victora et al. (2010) find that rapid growth faltering of HAZ was observed until 24 months of age, then plateauing from 25-59 months, while WAZ showed progressive and slow faltering through months 0-59, with the most rapid declines from 0-24 months. As a result, the child nutritional impacts of SI adoption decisions may also vary. In particular, the inclusion of the 6-24 months interaction terms allows us to test for differential effects of the SI treatment groups on the nutritional outcomes of children who are in the 'critical window of opportunity' for the promotion of optimal growth, health, and development, which is the 1,000 days from conception through the first two years of life.[16]

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[15] Zeng et al. (2017) find that a 0.25-hectare increase in improved maize variety area is associated with average HAZ and WAZ increases of 0.25 and 0.18 units, respectively, relative to sample means of -1.51 and -0.63.

[16] We also attempted to estimate models for children aged 6-24 months; however, these models do not converge.

In Table 1.3, the results including the interaction terms are presented in the upper panel and the results for children aged 25-59 months only are in the bottom panel. Together these results suggest that the positive effects of the “SI” category occur mainly among children aged 25-59 months. We continue to find no evidence of statistically significant effects for the “Sustainable” category. The negative effects of the “Intensification” category on HAZ are not robust to the model specification, as they cease to be statistically significant when we limit the sample to children aged 25-59 months. The lack of statistically significant effects of any SI categories on the HAZ and WAZ of children aged 6-24 months may be because these children are still being breastfed and largely dependent on complementary/weaning foods instead of consuming adult foods (Zeng et al., 2017; Tanzania Food and Nutrition Centre, 2014; Stephenson et al., 2017). Consistent with our findings, a recent study (Jain, 2018) finds that nutrient intake has no association with the HAZ of children aged 6-23 months in rural Bangladesh.

Table 1.3: CRE-METE estimates: Impacts on child nutritional outcomes with sub-sample analysis

Variables	HAZ	WAZ
Full-sample (N=2,486) with interaction terms		
Intensification	-0.400**	-0.238
	(0.192)	(0.176)
Sustainable	0.038	0.191
	(0.174)	(0.139)
SI	0.314*	0.423***
	(0.170)	(0.134)
Intensification×6-24 months	-0.129	-0.083
	(0.227)	(0.168)
Sustainable×6-24 months	0.182	0.026
	(0.119)	(0.090)
SI×6-24 months	0.077	0.062
	(0.172)	(0.146)
Sub-sample (N=1,411): children aged 25-59 months		
Intensification	-0.162	-0.104
	(0.207)	(0.158)
Sustainable	0.004	0.235
	(0.187)	(0.168)
SI	0.365**	0.439***
	(0.184)	(0.145)

Notes: Base category is "Non-adoption". ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. Standard errors clustered at the household level in parentheses. Selection terms (λ) excluded to conserve space.

Appendix Table 1A.6 shows the results for models that include the mother's BMI and age. These results suggest that the mother's BMI is positively correlated both child nutrition outcomes. Moreover, we still find that "SI" is positively correlated with both HAZ and WAZ.[17]

Overall, the robust finding across model specifications is that "SI" substantially enhances both HAZ and WAZ. This could be for the following reasons. First, note that 79% of the "SI" maize plots in Tanzania involve maize-legume intercropping (Table 1.1) and based on the results in Table 1A.7, which exclude organic fertilizer, the combined use of maize-legume intercropping

[17] Table 1A.6 also suggests that "Intensification" is negatively associated with HAZ and WAZ for children aged 6-59 months. However, we could not confirm that this holds for children aged 25-59 months because the model does not converge.

and inorganic fertilizer is a key driver of the positive “SI” effects on child nutrition.[18] The legume crops produced as a result may directly affect the diet composition of adopting households by providing needed protein and micronutrients (Messina 1999); this, in turn, may positively affect child nutrition. Indeed, as shown in appendix Table 1A.8, 90% of sample households in the “SI” group produce legumes, while only 19% and 31% of households in the “Non-adoption” and “Intensification” groups, respectively, produce legumes.[19] The table also indicates that maize-legume intercropping is the dominant way in which maize-growing households in Tanzania produce legumes. In addition, Stahley et al. (2012) report that the mean quantity of legumes consumed by producing households in Tanzania is double that consumed by purchasing households. Furthermore, these legume crops could help farmers to increase their crop income since per-kilogram prices for legumes are higher than maize prices (see Table 1A.3). Second, relative to farmers in the other treatment groups, households in the “SI” treatment group may have higher crop productivity or incomes due to synergistic effects when “Sustainable” practices are used jointly with inorganic fertilizer. Indeed, a review by Place et al. (2003) indicates that there is considerable evidence demonstrating positive effects on overall yields and net financial returns of combined use of inorganic fertilizer and organic soil fertility practices including animal manure and intercropping with legumes.

To explore if the “SI” effects come through the crop income and/or productivity pathways, we estimate CRE-METE models for two additional outcome variables: (1) gross value of crop production from the household’s maize plots as a proxy for crop income; and (2) an

[18] We tried to estimate a similar model with only organic fertilizer, inorganic fertilizer, and their combined use (excluding maize-legume intercropping) but it does not converge.

[19] The correlation between use of maize-legume intercropping and production of legumes in other ways is extremely low (-0.02).

index of crop output per acre on those plots as a proxy for productivity.[20] The associated CRE-METE results are shown in Table 1.4 and suggest that "SI" is indeed associated with increases in crop income and productivity on households' maize plots. "Intensification" is as well but the crop income effects are considerably and statistically larger for "SI". In contrast, "Sustainable" is associated with negative effects on crop income and no significant effects on productivity.

These results are consistent with the findings above of positive "SI" effects on HAZ and WAZ and no statistically significant "Sustainable" effects. Our results overall also suggest that not all income and productivity increases are created equal. Simply producing more maize via "Intensification" without involving legume crops may be insufficient to enhance child nutrition.

Table 1.4: CRE-METE estimates: Impacts on crop income and productivity

Variables	Crop income (Tanzanian Shillings)	Output index per acre
Intensification	350,835.572***	487.756***
	(114,258.251)	(131.930)
Sustainable	-114,241.755***	19.272
	(41,691.292)	(37.026)
SI	720,637.260***	531.401***
	(163,209.116)	(134.278)

Notes: N=1,871. Base category is "Non-adoption". ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. Standard errors clustered at the household level in parentheses.

[20] The denominator of the latter is the total acreage of the household's maize plots. The numerator (index Y_i) is calculated following Liu and Myers (2009) as $Y_i = \frac{\sum_j Y_{ij} P_j}{P_1}$, where Y_{ij} is the kilograms of crop *j* produced on farmer i's maize plots, P_j is the regional market price of crop *j*, and crop 1 is maize.

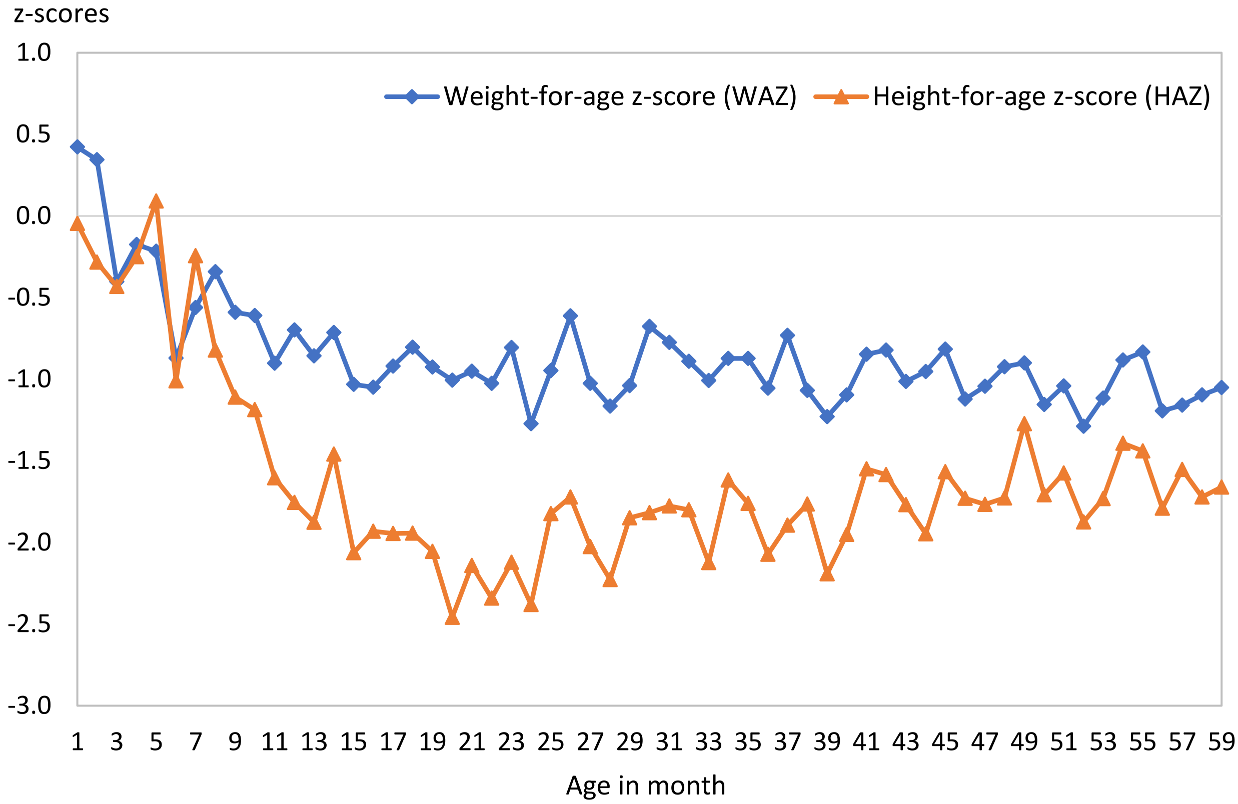
1.6 Conclusions and implications

In this study, we empirically estimated the effects of Tanzanian farm households' use of various SFM practices on their maize plots on the nutrition outcomes of young children in the household. The results consistently suggest that "SI" of maize production (joint use of inorganic fertilizer with maize-legume intercropping and/or organic fertilizer) is associated with increases in children's HAZ and WAZ compared to households that adopt none of the practices. These effects are mainly among children aged 25-59 months who, compared to younger children, are less likely to be breastfed and may be more directly affected by household diet changes associated with changes in agricultural practices. Joint use of maize-legume intercropping and inorganic fertilizer is a key driver of these results, and the effects appear to come through both crop income and productivity pathways. We also find no evidence that "Intensification" (use of inorganic fertilizer only) or "Sustainable" agricultural practices (use of organic fertilizer and/or maize-legume intercropping but no inorganic fertilizer) improve child nutrition outcomes. These results also link to the production diversity-dietary diversity/nutrition literature and suggest that crop diversification (proxied here by maize-legume intercropping) combined with intensification produces the most favorable child nutrition outcomes.

Our results have two main implications for agricultural policy and future research. First, given the potential benefits of joint use of inorganic fertilizer with maize-legume intercropping (and possibly organic fertilizer) for soil fertility, crop income, productivity, and child nutrition outcomes, it is important for policy makers to identify ways to promote use of such practices by Tanzanian maize farmers. (At present, Tanzania has much lower adoption rates of these practices than other countries in eastern and southern Africa such as Kenya, Malawi, and Ethiopia (Kassie et al., 2015a).) Further research is needed to identify cost-effective SI promotion strategies and our results do not speak directly to this question in a major way. However, based on our results, one general approach that *may* warrant further investigation (among others) is leveraging social learning to encourage SI of maize production. (Recall that the first stage results in appendix Table 1A.4 suggest that increases in the proportion of other households in a household's ward using inorganic fertilizer and maize-legume intercropping are associated with an increased probability of adoption of practices in the "SI" category by the household itself.) A second area in need of further research is if and how SI of agricultural systems more broadly (i.e., beyond maize) contributes to food security and child nutrition outcomes.

APPENDIX

Figure 1A.1: Mean WAZ and HAZ by age in months, relative to the WHO standard



Sources: Authors' calculations based on children under age 5 in maize growing households across the 2008/09, 2010/11, and 2012/13 waves of the TNPS.

Table 1A.1: Falsification test results (parameter estimates from CRE-POLS regressions for households in the "Non-adoption" category)

Variables	HAZ	WAZ
Child characteristics		
Child age (months)	0.013***	-0.005*
	(0.004)	(0.003)
Child gender (1=male)	-0.162*	-0.003
	(0.090)	(0.071)
Diarrhea (1=yes)	-0.113	-0.071
	(0.138)	(0.117)
Mother's education	-0.021	-0.018
	(0.021)	(0.018)
Monthly difference	0.009	0.030***
	(0.013)	(0.010)
T2 dummy	0.163*	-0.001
	(0.092)	(0.074)
T3 dummy	1.112***	0.433
	(0.209)	(0.440)
Household characteristics		
Head gender (1=male)	-0.066	-0.028
	(0.145)	(0.118)
Head age (years)	-0.033*	-0.032**
	(0.017)	(0.014)
Head education (years)	-0.007	0.005
	(0.018)	(0.014)
Spouse education (years)	0.008	0.009
	(0.025)	(0.020)
Family labor	-0.014	-0.018
	(0.074)	(0.027)
No. of female adults	0.033	-0.091
	(0.137)	(0.115)
No. of elderly	0.380	0.412
	(0.341)	(0.268)
No. of child	-0.057	0.023
	(0.092)	(0.065)
No. of siblings	-0.051	0.153
	(0.230)	(0.214)
Head marital status (1=yes)	0.081	0.050
	(0.120)	(0.097)
Off-farm income (1=yes)	-0.019	0.015
	(0.159)	(0.125)
Access to safe drinking water source	0.053	-0.042
(1=yes)	(0.120)	(0.091)
Safe drinking water	0.106	0.005
	(0.104)	(0.083)
Sanitation (toilet) (1=yes)	0.028	0.008
	(0.111)	(0.084)

Table 1A.1 (cont'd)

Variables	HAZ	WAZ
Agricultural characteristics		
Total cultivated land (acres)	-0.019	-0.024**
	(0.019)	(0.012)
Own plot (1=yes)	-0.271*	-0.055
	(0.155)	(0.140)
Market distance (km)	-0.000	0.002
	(0.003)	(0.002)
Farm assets (1,000 TZS)	0.000	0.000**
	(0.000)	(0.000)
Livestock (1=yes)	0.037	0.050
	(0.103)	(0.082)
Input and output prices		
Maize price (TZS/kg)	0.000	-0.000
	(0.000)	(0.000)
Bean price (TZS/kg)	0.000	0.001**
	(0.000)	(0.000)
Groundnut price (TZS/kg)	0.000	0.000
	(0.000)	(0.000)
Inorganic fertilizer price (TZS/kg)	-0.001*	-0.000
	(0.000)	(0.000)
Community characteristics		
Govt. health/hospital (1=yes)	0.045	0.017
	(0.094)	(0.077)
Instrumental variables		
Electoral threat	0.002	-0.099
	(0.126)	(0.073)
Number of subsidized fertilizer vouchers	-0.000	-0.000
	(0.000)	(0.000)
Proportion receiving agricultural advice	0.001	-0.001
	(0.002)	(0.002)
Proportion adopting inorganic fertilizer	0.001	0.001
	(0.003)	(0.002)
Proportion adopting maize-legume IC	-0.000	-0.002
	(0.002)	(0.001)
Constant	-2.952***	-1.572***
	(0.460)	(0.355)

Notes: Sample size is 1,084 individuals in the "Non-adoption" category. Time-averages of household level variables to control for time-constant unobserved heterogeneity were included in the model but not reported in Table 1A.1. ***, **, and * denote statistically significance at the 1%, 5%, and 10% levels, respectively. Standard errors clustered at the household level in parentheses.

Table 1A.2: Summary statistics for child nutritional status and child characteristics used in the analysis

Variables	Variable description	Mean values for each SI category				Mean of all	SD of all
		N	I	S	SI		
Child nutritional status							
HAZ	Height-for-age z-score	-1.86	-1.82	-1.76*	-1.98	-1.82	1.31
Stunted children	1 = yes if HAZ < -2	0.47	0.46	0.46	0.48	0.47	0.50
WAZ	Weight-for-age z-score	-1.02	-0.90	-0.94*	-1.02	-0.98	1.03
Underweighting children	1 = yes if WAZ < -2	0.15	0.13	0.15	0.15	0.15	0.36
Control variables							
Child characteristics							
Child age	Age of children under age 5 (months)	37.72	36.75	37.24	37.48	37.44	12.79
Child gender	Gender of the child (1 = male)	0.48	0.48	0.50	0.45	0.49	0.50
Diarrhea	1 = yes if the child had diarrhea in the past 2 weeks	0.09	0.08	0.10	0.09	0.09	0.29
Mother's education	Highest grade completed by the child's mother (years)	4.49	5.63***	4.55	5.59***	4.66	3.44
Monthly difference	Time difference between maize harvest and measurement of the child's nutritional status	10.10	9.88	9.86	10.10	9.98	4.15
T1 dummy (excluded)	1 = yes if the child is observed once in any of the three waves	0.64	0.60	0.68**	0.52***	0.65	0.48
T2 dummy	1 = yes if the child is observed twice in any of the three waves	0.35	0.40	0.31*	0.48***	0.35	0.48
T3 dummy	1 = yes if the child is observed in all three waves	0.01	0.00***	0.00	0.00***	0.00	0.07
Number of observations		1084	149	1071	182	2486	

Notes: N, I, S, and SI indicate Non-adoption, Intensification, Sustainable, and SI, respectively. A two-sample *t*-test was used to compare the means of variables between each SI treatment group (I, S, and SI) and the base category (N) under the assumption of unequal variance. SD is standard deviation. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Table 1A.3: Summary statistics for other control variables used in the analysis

Variables	Variable description	Mean values for each SI category				Mean of all	SD of all
		N	I	S	SI		
Control variables							
Household characteristics							
Head gender	Gender of the household head (1 = male)	0.83	0.91***	0.82	0.89*	0.84	0.37
Head age	Age of the household head (years)	43.44	41.02*	44.81*	40.30***	43.59	14.06
Head education	Highest grade completed by the household head (years)	4.57	6.60***	4.52	6.32***	4.82	3.31
Spouse education	Highest grade completed by the spouse	3.78	5.47***	3.91	5.57***	4.09	3.39
Family labor	Number of adults (15-64 years old) per acre	1.02	0.96	1.09	1.08	1.05	1.41
No. of female adults	Number of female adults in the household	1.54	1.52	1.75***	1.50	1.62	1.05
No. of elderly	Number of household members above 65 years	0.22	0.13*	0.23	0.10***	0.21	0.49
No. of child	Number of household members below 15 years	3.69	3.32**	4.11***	3.76	3.84	2.17
No. of siblings	Number of siblings of children under age 5	0.06	0.02***	0.07	0.01***	0.06	0.33
Head marital status	1 = yes if the HH head got married	0.70	0.74	0.70	0.75	0.71	0.46
Off-farm income	1 = yes if the HH earns other income	0.43	0.52**	0.50***	0.58***	0.48	0.50
Access to safe drinking water source	1 = yes if the HH has safe drinking water source (e.g., piped or protected water)	0.22	0.40***	0.22	0.23	0.23	0.42
Safe drinking water	1 = yes if the HH does drink boiled/bottled/treated water	0.21	0.33**	0.26**	0.25	0.24	0.43
Sanitation (toilet)	1 = yes if the HH has a private toilet	0.80	0.94***	0.80	0.97***	0.82	0.38
Agricultural characteristics							
Total cultivated land	Total land area (acres) cultivated	6.99	6.15	7.99	7.51	7.38	19.01
Own plot	1 = yes if the HH owns at least one maize plot	0.92	0.90	0.92	0.97***	0.92	0.27
Market distance	Distance to the nearest market (km)	12.16	10.95	11.47	11.68	11.76	13.05
Farm assets	Total value of farm implements and machinery (100,000 TZS)	16.06	8.79	29.12***	5.16***	20.04	89.84
Livestock	1 = yes if the HH has livestock (cattle, goats/sheep, pigs, or donkeys)	0.41	0.45	0.58***	0.54***	0.49	0.50

Table 1A.3 (cont'd)

Variables	Variable description	Mean values for each SI category				Mean of all	SD of all
		N	I	S	SI		
Input and output prices							
Maize price	Maize (grain) market price at district level (TZS/kg)	469.81	440.56	474.76	419.93***	465.99	202.33
Bean price	Bean market price at district level (TZS/kg)	1296.55	1267.65	1295.97	1290.15	1293.87	325.53
Groundnut price	Groundnut market price at district level (TZS/kg)	1675.66	1690.78	1678.77	1656.75	1676.48	561.07
Inorganic fertilizer price	Inorganic fertilizer price at district level (TZS/kg)	1131.46	996.04***	1178.80**	940.40***	1126.81	414.54
Community characteristics							
Govt. health/hospital	1 = yes if there is a governmental health center/hospital in the community	0.45	0.49	0.43	0.45	0.44	0.50
<u>*Instrumental variables*</u>							
Electoral threat	Proportion of votes for the runner-up divided by the proportion of votes for the presidential winner	0.28	0.17***	0.28	0.20**	0.27	0.54
Number of subsidized fertilizer vouchers	Number of subsidized fertilizer vouchers distributed to the household's region (thousand)	58.33	107.03***	48.84***	120.23***	62.54	68.16
Proportion receiving agricultural advice	Proportion of other households in the ward that got advice on agricultural production	9.85	20.52***	10.20	22.71***	11.71	18.38
Proportion using inorganic fertilizer	Proportion of other households in the ward that use inorganic fertilizer	6.98	54.43***	9.22**	59.43***	15.15	27.81
Proportion using maize-legume IC	Proportion of other households in the ward that use maize-legume intercropping	33.70	44.66***	48.48***	58.85***	42.41	33.36
Number of observations		838	126	762	145	1871	

Notes: N, I, S, and SI indicate Non-adoption, Intensification, Sustainable, and SI, respectively. A two-sample *t*-test was used to compare the means of variables between each SI treatment group (I, S, and SI) and the base category (N) under the assumption of unequal variance. SD is standard deviation. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. TZS = Tanzania Shillings.

Table 1A.4: CRE mixed multinomial logit estimates of the determinants of adoption of each SI category (relative to the "Non-adoption" base category)

Variables	Intensification	Sustainable	SI
Child characteristics			
Child age (months)	-0.020*	0.005	0.000
	(0.010)	(0.004)	(0.009)
Child gender (1=male)	-0.001	0.066	-0.113
	(0.272)	(0.119)	(0.247)
Diarrhea (1=yes)	-0.051	0.248	0.586
	(0.455)	(0.210)	(0.408)
Mother's education	0.003	-0.003	0.050
	(0.062)	(0.033)	(0.062)
Monthly difference	-0.034	-0.002	0.020
	(0.044)	(0.019)	(0.033)
T2 dummy	-0.296	-0.101	0.069
	(0.323)	(0.137)	(0.283)
T3 dummy	-49.806***	-1.296	-50.018***
	(0.736)	(0.802)	(0.813)
Household characteristics			
Head gender (1=male)	0.719	-0.243	0.011
	(0.511)	(0.230)	(0.495)
Head age (years)	-0.024	-0.010	0.034
	(0.059)	(0.038)	(0.056)
Head education (years)	0.091	-0.021	0.076
	(0.066)	(0.028)	(0.053)
Spouse education (years)	-0.010	-0.000	0.010
	(0.077)	(0.038)	(0.068)
Family labor	-0.207	0.019	0.232
	(0.321)	(0.098)	(0.183)
No. of female adults	-0.480	-0.491*	-0.703*
	(0.377)	(0.279)	(0.382)
No. of elderly	-0.164	0.013	-0.040
	(0.637)	(0.788)	(0.870)
No. of child	0.482**	0.022	0.354*
	(0.206)	(0.112)	(0.182)
No. of siblings	-0.101	-0.138	-4.256
	(0.659)	(0.538)	(2.800)
Head marital status (1=yes)	0.283	0.090	0.427
	(0.334)	(0.187)	(0.342)
Off-farm income (1=yes)	0.422	0.521*	1.441***
	(0.614)	(0.277)	(0.520)
Access to safe drinking water source	0.826**	0.184	-0.331
(1=yes)	(0.330)	(0.184)	(0.339)
Safe drinking water	0.805**	0.255	0.351
	(0.336)	(0.178)	(0.328)
Sanitation (toilet) (1=yes)	1.633***	-0.103	1.417**
	(0.629)	(0.195)	(0.718)

Table 1A.4 (cont'd)

Variables	Intensification	Sustainable	SI
Agricultural characteristics			
Total cultivated land (acres)	0.037	0.046	-0.043
	(0.054)	(0.033)	(0.058)
Own plot (1=yes)	0.128	-0.223	1.305**
	(0.469)	(0.265)	(0.607)
Market distance (km)	-0.020*	-0.004	0.001
	(0.011)	(0.006)	(0.012)
Farm assets (1,000 TZS)	0.000	0.000	-0.000
	(0.000)	(0.000)	(0.000)
Livestock (1=yes)	0.161	0.874***	0.883***
	(0.350)	(0.174)	(0.325)
Input and output prices			
Maize price (TZS/kg)	0.002	-0.002*	-0.002
	(0.002)	(0.001)	(0.002)
Bean price (TZS/kg)	-0.000	-0.000	-0.000
	(0.001)	(0.001)	(0.001)
Groundnut price (TZS/kg)	0.000	0.000	-0.000
	(0.001)	(0.000)	(0.000)
Inorganic fertilizer price (TZS/kg)	0.001	0.000	0.001
	(0.001)	(0.000)	(0.001)
Community characteristics			
Govt. health/hospital (1=yes)	0.007	-0.030	-0.542*
	(0.290)	(0.159)	(0.324)
Instrumental variables			
Electoral threat	-0.711	0.141	0.804***
	(0.727)	(0.185)	(0.298)
Number of subsidized fertilizer	0.000	-0.000***	0.000
vouchers	(0.000)	(0.000)	(0.000)
Proportion receiving agricultural	-0.002	-0.007	-0.002
advice	(0.007)	(0.005)	(0.008)
Proportion adopting inorganic	0.063***	0.010**	0.066***
fertilizer	(0.007)	(0.004)	(0.006)
Proportion adopting maize-legume	-0.001	0.016***	0.017***
IC	(0.005)	(0.002)	(0.005)
Constant	-5.277***	-1.468**	-8.840***
	(1.451)	(0.719)	(1.553)

Notes: Sample size is 2,486 individuals (1,873 households). Time-averages of household level variables to control for time-constant unobserved heterogeneity were included in the model but not reported in Table 1A.4. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. Standard errors clustered at the household level in parentheses.

Table 1A.5: Second stage estimates for child nutritional outcomes

Variables	Full-sample (6-59 mo.)		Full-sample with interactions		Sub-sample (25-59 mo.)	
	HAZ	WAZ	HAZ	WAZ	HAZ	WAZ
Child characteristics						
Child age (months)	0.009***	-0.004**	0.011**	-0.006*	0.014***	-0.009***
	(0.003)	(0.002)	(0.004)	(0.003)	(0.004)	(0.003)
Child gender (1=male)	-0.168***	-0.018	-0.167***	-0.017	-0.017	0.080
	(0.060)	(0.048)	(0.060)	(0.048)	(0.068)	(0.056)
Diarrhea (1=yes)	-0.203**	-0.095	-0.204**	-0.097	-0.192	-0.058
	(0.093)	(0.076)	(0.093)	(0.076)	(0.135)	(0.123)
Mother’s education	0.001	-0.012	0.000	-0.012	-0.001	-0.019
	(0.015)	(0.012)	(0.015)	(0.012)	(0.016)	(0.014)
Monthly difference	0.009	0.017**	0.008	0.018**	0.013	0.020***
	(0.009)	(0.007)	(0.009)	(0.007)	(0.010)	(0.008)
T2 dummy	0.055	-0.011	0.053	-0.008	-0.241	-0.026
	(0.068)	(0.053)	(0.069)	(0.053)	(0.184)	(0.138)
T3 dummy	1.140***	0.733	1.124***	0.731		
	(0.250)	(0.464)	(0.241)	(0.458)		
Household characteristics						
Head gender (1=male)	0.117	0.059	0.113	0.057	0.047	0.025
	(0.108)	(0.083)	(0.107)	(0.083)	(0.122)	(0.096)
Head age (years)	-0.002	0.005	-0.003	0.005	0.008**	0.006**
	(0.011)	(0.010)	(0.011)	(0.010)	(0.004)	(0.003)
Head education (years)	0.005	0.008	0.004	0.008	0.006	0.006
	(0.013)	(0.010)	(0.013)	(0.010)	(0.014)	(0.011)
Spouse education (years)	0.003	0.014	0.003	0.013	0.012	0.026*
	(0.018)	(0.014)	(0.018)	(0.014)	(0.019)	(0.015)
Family labor	-0.026	-0.026	-0.028	-0.025	0.025	0.025
	(0.052)	(0.028)	(0.052)	(0.028)	(0.024)	(0.019)
No. of female adults	-0.066	-0.046	-0.067	-0.045	-0.002	-0.002
	(0.074)	(0.063)	(0.073)	(0.064)	(0.036)	(0.029)
No. of elderly	-0.008	-0.024	-0.009	-0.025	-0.022	0.041
	(0.315)	(0.209)	(0.314)	(0.211)	(0.091)	(0.075)
No. of child	-0.054	0.021	-0.051	0.020	-0.012	-0.021
	(0.037)	(0.036)	(0.037)	(0.037)	(0.017)	(0.016)
No. of siblings	0.098	0.241**	0.097	0.240**	0.087	0.049
	(0.160)	(0.110)	(0.160)	(0.108)	(0.099)	(0.064)
Head marital status (1=yes)	0.092	0.031	0.090	0.033	0.139	0.067
	(0.086)	(0.066)	(0.086)	(0.065)	(0.100)	(0.075)
Off-farm income (1=yes)	-0.086	-0.041	-0.077	-0.039	0.178**	0.166***
	(0.114)	(0.088)	(0.115)	(0.088)	(0.078)	(0.064)
Access to safe drinking water	0.081	-0.004	0.078	-0.005	-0.067	-0.057
source (1=yes)	(0.083)	(0.064)	(0.083)	(0.064)	(0.087)	(0.066)
Safe drinking water	0.099	0.026	0.101	0.026	0.047	0.078
	(0.072)	(0.058)	(0.072)	(0.058)	(0.078)	(0.065)
Sanitation (toilet) (1=yes)	-0.234***	-0.080	-0.232***	-0.079	-0.171*	-0.096
	(0.088)	(0.071)	(0.088)	(0.072)	(0.096)	(0.076)
Agricultural characteristics						
Total cultivated land (acres)	-0.010	-0.006	-0.011	-0.006	0.001	0.001**
	(0.009)	(0.007)	(0.009)	(0.007)	(0.001)	(0.001)
Own plot (1=yes)	-0.030	0.046	-0.028	0.047	-0.008	0.026
	(0.119)	(0.108)	(0.119)	(0.108)	(0.137)	(0.132)

Table 1A.5 (cont'd)

Variables	Full-sample (6-59 mo.)		Full-sample with interactions		Sub-sample (25-59 mo.)	
	HAZ	WAZ	HAZ	WAZ	HAZ	WAZ
Market distance (km)	-0.001	0.001	-0.001	0.001	0.004	0.003
	(0.002)	(0.002)	(0.002)	(0.002)	(0.003)	(0.002)
Farm assets (1,000 TZS)	0.000	0.000	0.000	0.000	0.000***	0.000***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Livestock (1=yes)	0.041	0.033	0.042	0.033	-0.024	-0.036
	(0.073)	(0.061)	(0.073)	(0.061)	(0.085)	(0.067)
Input and output prices						
Maize price (TZS/kg)	0.001**	0.000	0.001**	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Bean price (TZS/kg)	0.000	0.000	0.000	0.000	0.000**	0.000*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Groundnut price (TZS/kg)	0.000**	0.000	0.000**	0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Inorganic fertilizer price (TZS/kg)	-0.000	0.000	-0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Community characteristics						
Govt. health/hospital (1=yes)	-0.008	0.017	-0.006	0.016	0.049	0.028
	(0.067)	(0.055)	(0.067)	(0.054)	(0.073)	(0.061)
SI category						
Intensification	-0.463***	-0.266	-0.400**	-0.238	-0.162	-0.104
	(0.176)	(0.170)	(0.192)	(0.176)	(0.207)	(0.158)
Sustainable	0.116	0.200	0.038	0.191	0.004	0.235
	(0.160)	(0.133)	(0.174)	(0.139)	(0.187)	(0.168)
SI	0.355**	0.453***	0.314*	0.423***	0.365**	0.439***
	(0.155)	(0.125)	(0.170)	(0.134)	(0.184)	(0.145)
Selection terms						
Intensification (λ_I)	0.443**	0.647***	0.450**	0.638***	0.328**	0.340***
	(0.177)	(0.125)	(0.176)	(0.135)	(0.160)	(0.123)
Sustainable (λ_S)	-0.232	-0.103	-0.235	-0.105	-0.061	-0.286
	(0.151)	(0.188)	(0.154)	(0.195)	(0.214)	(0.194)
SI (λ_{SI})	-0.592***	-0.557***	-0.589***	-0.545***	-0.715***	-0.596***
	(0.125)	(0.155)	(0.129)	(0.167)	(0.227)	(0.134)
Age dummy and Interaction terms						
6-24 months of age dummy			-0.038	-0.079		
			(0.115)	(0.090)		
Intensification×6-24 months of age			-0.129	-0.083		
			(0.227)	(0.168)		
Sustainable×6-24 months of age			0.182	0.026		
			(0.119)	(0.090)		
SI×6-24 months of age			0.077	0.062		
			(0.172)	(0.146)		
Constant	-3.285***	-1.771***	-3.301***	-1.679***	-3.584***	-1.650***
	(0.318)	(0.247)	(0.346)	(0.264)	(0.343)	(0.287)
Joint test for selection terms (χ^2)	13,265***	10,952***	11,849***	10,894***	15,141***	13,524***
Observations	2,486	2,486	2,486	2,486	1,411	1,411

Notes: Time-averages of household level variables to control for time-constant unobserved heterogeneity were included in the full-sample models but not reported in Table 1A.5. Base category is "Non-adoption". ***, **, and * denote statistically significance at the 1%, 5%, and 10% levels, respectively. Standard errors clustered at the household level in parentheses.

Table 1A.6: CRE-METE model estimates with controls for mother's age and BMI

Variables	HAZ	WAZ
Full sample (children aged 6-59 months)		
Intensification	-0.630***	-0.371***
	(0.160)	(0.136)
Sustainable	0.091	0.034
	(0.125)	(0.105)
SI	0.388***	0.330**
	(0.140)	(0.150)
Mother's age	0.008	-0.001
	(0.005)	(0.004)
Mother's BMI	0.029***	0.054***
	(0.010)	(0.008)
Selection terms(λ)		
Intensification (λ_I)	0.789***	0.502***
	(0.088)	(0.122)
Sustainable (λ_S)	-0.107	-0.051
	(0.138)	(0.121)
SI (λ_{SI})	-0.642***	-0.547***
	(0.103)	(0.162)
Full-sample with interaction terms		
Intensification	-0.599***	-0.313**
	(0.175)	(0.157)
Sustainable	-0.018	0.036
	(0.138)	(0.114)
SI	0.346**	0.302*
	(0.148)	(0.164)
Intensification×6-24 months of age	-0.085	-0.164
	(0.245)	(0.180)
Sustainable×6-24 months of age	0.240*	-0.006
	(0.128)	(0.095)
SI×6-24 months of age	0.084	0.047
	(0.179)	(0.148)
Mother's age	0.008*	-0.001
	(0.005)	(0.004)
Mother's BMI	0.029***	0.054***
	(0.010)	(0.008)

Notes: N=2,155. Base category is "Non-adoption". ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. Standard errors clustered at the household level in parentheses. The selection terms (λ) for the full-sample with interaction terms are excluded to conserve space. The corresponding model for the sub-sample of children aged 25-59 months does not converge.

Table 1A.7: CRE-METE model estimates: Impacts of the adoption of inorganic fertilizer, maize-legume intercropping, and their joint use on child nutritional outcomes – full and sub-sample analysis

Variables	HAZ	WAZ
Full sample (N=2,486): children aged 6-59 months		
Inorganic fertilizer	-0.349**	-0.287
	(0.154)	(0.328)
Maize-legume intercropping	0.273*	0.084
	(0.146)	(0.291)
Joint use	0.404***	0.406**
	(0.165)	(0.176)
Selection terms(λ)		
Inorganic fertilizer (λ_F)	0.532***	0.501
	(0.138)	(0.448)
Maize-legume intercropping (λ_{IC})	-0.360**	-0.125
	(0.154)	(0.368)
Joint use (λ_{Joint})	-0.637***	-0.563**
	(0.148)	(0.235)
Full-sample (N=2,486) with interaction terms		
Inorganic fertilizer	-0.301*	-0.270
	(0.166)	(0.622)
Maize-legume intercropping	0.247	0.082
	(0.152)	(0.537)
Joint use	0.436**	0.352
	(0.175)	(0.245)
Inorganic fertilizer×6-24 months of age	-0.119	-0.114
	(0.212)	(0.168)
Maize-legume intercropping×6-24 months of age	0.054	-0.043
	(0.121)	(0.094)
Joint use×6-24 months of age	-0.079	0.092
	(0.176)	(0.161)
Sub-sample (N=1,411): children aged 25-59 months		
Inorganic fertilizer	-0.182	-0.078
	(0.196)	(0.139)
Maize-legume intercropping	0.025	0.216
	(0.177)	(0.137)
Joint use	0.403***	0.416***
	(0.200)	(0.143)

Notes: Base category is "Non-adoption". ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. Standard errors clustered at the household level in parentheses. The selection terms (λ) for the full-sample with interaction terms and sub-sample analyses are excluded to conserve space.

Table 1A.8: Percentage of sample households producing legumes by household-level SI category

Type of legume production	Household-level SI category: Non-adoption	Intensification	Sustainable	SI	Total
(a) Only via maize-legume intercropping	8.2	10.3	76.0	77.2	41.3
(b) Only on pure-stand legume plots or via intercropping legumes with non-maize crops	9.4	17.5	2.4	4.1	6.7
(c) Both maize-legume intercropping <u>and</u> pure-stand legumes or intercropping legumes with non-maize crops	1.7	3.2	9.3	8.3	5.4
(d) Any legume production (a, b, or c)	19.3	31.0	87.7	89.6	53.4

Notes: N=1,871 sample households. Values in row (a) for Non-adoption and Intensification are not zero because household-level SI categories are used for this table and recall that these categories are based on the SI category that accounts for the largest share of the households' maize plots' area.

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CHAPTER 2

THE IMPACTS OF SUSTAINABLE INTENSIFICATION OF MAIZE PRODUCTION ON HOUSEHOLD CROP INCOME, PRODUCTIVITY, AND FOOD ACCESS IN RURAL TANZANIA

2.1 Introduction

A key challenge in sub-Saharan Africa (SSA) is how to simultaneously raise agricultural productivity and household incomes while achieving food security and environmental sustainability goals. In many SSA countries, low crop yields are closely linked to degraded and infertile soils, which are caused by a variety of factors including continuous monocropping, inadequate investment in organic matter recycling, and climatic variability (Ngwira et al., 2012; Manda et al., 2016a). Given that agriculture is the main source of livelihood for the majority of rural small-scale farm households in SSA, the use of more efficient farming practices or technologies is crucial for alleviating food insecurity (Di Falco and Veronesi, 2013; Khonje et al., 2018). For example, conventional agricultural intensification via improved seed and inorganic fertilizer can improve crop yields in the short-term. This could, in turn, increase the quantity of food available for home consumption or increase household income, which could then be used to purchase more or better quality food, thereby contributing to improved food access, an important dimension of food security.[21] However, there is growing agreement that increased use of these inputs alone is insufficient to intensify agricultural production over the long-term (The Montpellier Panel, 2013; Kassie et al. 2015a). In addition, continuous use of inorganic fertilizer without complementary organic inputs and management practices could result

[21] Food security is defined as when "all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (FAO 1996). Food security consists of four dimensions: food availability, access, utilization, and stability.

in negative environmental externalities (Pingali, 2012). Thus, conventional agricultural intensification may not be a viable solution for achieving and maintaining food security and environmental sustainability in the long-run.

Researchers and policymakers are therefore increasingly interested in how to achieve *sustainable* agricultural intensification (SI) and to leverage it to food security and environmental objectives (Godfray 2015). At the core of SI is the goal of increasing agricultural yields without bringing new land under cultivation, while minimizing adverse environmental impacts (Godfray et al. 2010; Pretty et al. 2011). Holden (2018) and Jayne et al. (2019) suggest that the combined use of inorganic fertilizer and organic soil fertility practices (which is a form of Integrated Soil Fertility Management (ISFM)) is an approach to SI.[22]

Given the potential of SI of crop production to address low crop yields and food insecurity issues, the main objective of this study is to estimate the impacts of SI on smallholder farm household productivity, incomes, and food security – something that has not been rigorously examined in the previous literature. Instead, most previous studies on the household welfare and food security effects of various farming practices have focused on *individual* practices like minimum or zero tillage, improved maize/wheat varieties, inorganic fertilizer, or cereal-legume rotation or intercropping (e.g., Jaleta et al., 2016; Zeng et al. 2015; Shiferaw et al. 2014; Magrini and Vigani, 2016; Sauer et al., 2018). However, the use of any one of these practices individually is unlikely to contribute to SI. Moreover, while there are a handful of empirical studies on the crop yield and household income effects of farmers' use of *combinations* of agricultural practices that could contribute to SI (e.g., Manda et al. (2016a) and Khonje et al. (2018) for Zambia; Kassie et al. (2015b) for Malawi; and Teklewold et al. (2013) and Kassie et

[22] Holden (2018) also lists Conservation Agriculture (CA) as an approach to SI. CA is based on three principles: crop rotation/intercropping with legumes, permanent soil cover, and minimum or zero tillage.

al. (2018) for Ethiopia), none of these studies estimate the effects of the practices on household food security.

To fill these gaps, this study uses nationally representative household panel survey data from Tanzania (the Tanzania National Panel Surveys (TNPS) of 2008/09, 2010/11, and 2012/13 – described below) to estimate the effects on rural maize-growing households' productivity, net crop income, and food access of the use of various combinations of three important soil fertility management (SFM) practices that could contribute to SI of maize-based production systems in Tanzania.[23] The three focal SFM practices are inorganic fertilizer, organic fertilizer, and maize-legume intercropping.[24] Understanding SI in the context of maize-based production systems is particularly important in Tanzania because maize provides about half the household calories for smallholder farms across Tanzania (Cochrane and D'Souza 2015) and the area planted with maize accounts for 75% of the total cultivated area in the country (Tanzania National Bureau of Statistics (TNBS) 2014). We follow Kim et al. (in press) and group the eight possible combinations of these three SFM practices on a given maize plot into four SI categories: (i) "Non-adoption" (use of none of the practices); (ii) "Intensification" (use of inorganic fertilizer only); (iii) "Sustainable" (use of organic fertilizer (animal manure or compost), maize-legume intercropping, or both, but no inorganic fertilizer); and (iv) "SI" (use of inorganic fertilizer jointly with at least one of the practices in the "Sustainable" category). The rationale for these groupings is discussed further below and at length in Kim et al. (in press) but, briefly, joint use of inorganic fertilizer with maize-legume intercropping and/or organic fertilizer on a given maize

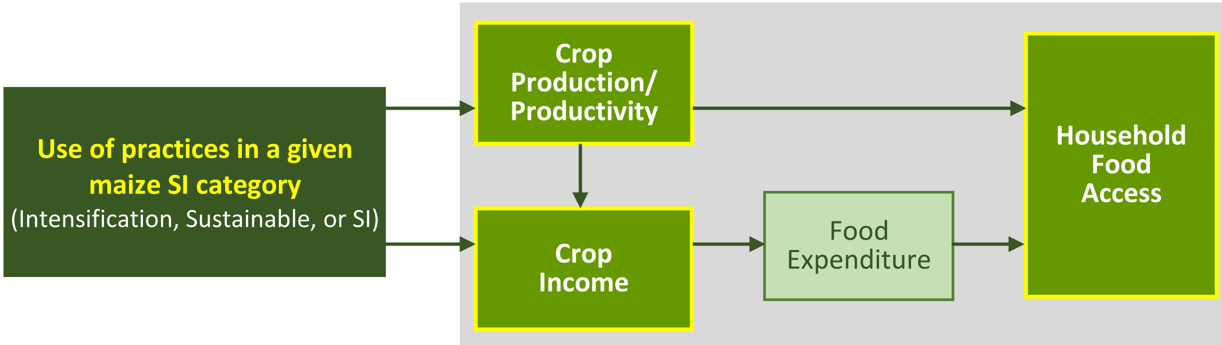
[23] We focus on food access due to data constraints that limit our ability to examine impacts on the other three dimensions of food security.
[24] There are other practices – for example, maize-legume rotation and minimum tillage – that have the potential to contribute to SI, but they are not widely used in Tanzania as of yet and are not captured in the TNPS data. The three SFM practices on which we focus are the most common ones used in maize-based systems in rural Tanzania.

plot is considered "SI" of maize production because such joint use is expected to raise productivity while preserving or enhancing soil health due to synergistic or complementary effects among the practices.

We estimate the effects of use of practices in the various SI categories on net crop income and productivity in addition to food access because crop income and food production/productivity are considered the two main potential impact pathways through which changes in cropping practices including the SFM practices studied here are likely to affect household food access as well as food security and nutrition more broadly (Herforth and Harris, 2014; Kumar et al., 2015).[25] For example, households' use of the practice(s) in each SI category relative to "Non-adoption" could improve crop production or productivity in terms of the quality and/or quantity of crops produced on their maize plot, which household members could consume directly. In addition, it could increase a household's crop income through generating larger quantities of the crops that can be sold at the market, which, in turn, allows farmers to purchase more and/or better quality food (see Figure 2.1). We consider several measures of food access (described further below): household food expenditure per adult equivalent, a modified version of the standard household dietary diversity score (HDDS), and the household's food consumption score (FCS).

[25] The third potential pathway is women's empowerment (Herforth and Harris 2014) but the TNPS data do not contain information that would enable empirical analysis of this pathway.

Figure 2.1: Conceptual pathways between SI of maize production and household food access



Sources: Modified from Herforth and Harris (2014) and Kim et al. (in press)

This study makes several contributions to the previous literature. First, to our knowledge, it is the first empirical examination of the impacts of households' use of *combinations* of SFM practices (as opposed to individual practices) on household food access. Second, we go beyond previous studies on the impacts of combined use of agricultural practices by considering joint use of maize-legume intercropping with inorganic fertilizer and rigorously examining the effects of such joint use on household crop income, productivity, and food access. Some previous studies (Kassie et al., 2015b; Kassie et al., 2018) consider maize-legume intercropping in their analyses but group it with maize-legume rotation in a combined variable for ‘crop diversification’. Third, we use nationally representative household panel survey data, whereas most of the previous studies that are closely related to this study use either cross-sectional or panel data but not nationally representative panel data (Manda et al. 2016a; Khonje et al., 2018; Kassie et al. 2015b, 2018; Teklewold et al. 2013). The data used here should improve both the external validity of our findings (because the data are nationally representative) as well as the internal validity thereof (because we use panel data methods – namely, the Mundlak-Chamberlain correlated random effects (CRE) approach combined with multinomial endogenous switching regression (MESR) methods – to control for selection bias). Finally, the study complements and extends

Kim et al. (in press), which estimates the effects of the use of the same set of practices we consider here on child nutrition outcomes among rural maize-growing households in Tanzania but does not estimate the effects on food access and makes only a cursory examination of the effects of the practices on productivity and incomes. Kim et al. find positive effects of use of practices in the “SI” group on child nutrition outcomes, which begs the question of whether this is also the case for household food access-related outcomes. Moreover, understanding if there are such effects on household food access could help to further explain the pathways through which SI of maize production affects child nutrition.

Our CRE-MESR results suggest that relative to Non-adoption, the use of practices in each of the other three SI categories (i.e., “Intensification”, “Sustainable”, and “SI”) has a positive effect on households’ net crop income-related outcomes and crop productivity. Of these three sets of practices, using practices in the “SI” group was the most effective, providing the largest effects on net crop income and net crop income per adult equivalent. On the other hand, the adoption effects of practices in the “Sustainable” category were small relative to the other two groups. We also find that households’ use of packages in the “SI” group is associated with increases in all three food access outcomes, while the effects of using practices in the “Intensification” and “Sustainable” groups differ across food access outcomes in terms of statistical significance and the extent of the effects.

The rest of this study is organized as follows. Section 2.2 provides background information on the use of the focal SFM practices in Tanzania. Section 2.3 outlines the econometric approaches. Section 2.4 describes the data and food security outcome variables used in this study. The results are presented and discussed in Section 2.5 and the last section draws conclusions and policy implications.

2.2 SI of maize production in Tanzania

We begin this section by briefly describing the rationale for the SI categories used here. The reader is referred to Kim et al. (in press) for a much more detailed discussion of the rationale, including extensive references to empirical evidence supporting the categorizations. We then describe the prevalence of use of practices in the various SI categories in rural Tanzania.

The main reason that use of inorganic fertilizer only ("Intensification") is not considered "SI" is because of the potentially negative soil health and environmental impacts of continuous use of inorganic fertilizer without complementary SFM practices (Matson et al., 1997; Pingali, 2012; Petersen and Snapp, 2015; Bronick and Lal, 2005). For this reason, although use of inorganic fertilizer can raise maize yields in the short-run, these yield increases are unlikely to be sustained in the long-run. The practices in the "Sustainable" category (organic fertilizer and maize-legume intercropping) can improve soil fertility in the longer-run and use locally available resources but in the absence of inorganic fertilizer, they are unlikely to appreciably increase crop productivity, particularly in the short-run. However, when inorganic fertilizer is used jointly with maize-legume intercropping or organic fertilizer, there are several potential synergistic or complementary effects which can result in higher productivity while maintaining or improving soil fertility. For instance, improving soil organic matter (SOM) levels through the application of organic fertilizer or maize-legume intercropping could increase maize yield response to inorganic fertilizer (Marenya and Barrett 2009; Jayne et al. 2018). Moreover, there is empirical evidence that the packages in the "SI" group can considerably improve crop yields or farmers' returns. For instance, Waddington et al. (2007) observed during the years from 1993 to 2006 in Zimbabwe that maize yields were about two times larger on average with a joint application of maize-legume intercropping and inorganic fertilizer than with maize-legume intercropping alone.

Moreover, work by Mekuria and Waddington (2002) in Zimbabwe suggests that maize gross margins per hectare increased by about 7.5 times when inorganic fertilizer was jointly used with animal manure compared to when the same quantity of inorganic fertilizer was used without manure.

Table 2.1 summarizes the prevalence of use of the three focal SFM practices and combinations thereof on maize plots in Tanzania. Out of 5,419 maize plots in the sample (TNPS 2008/09, 2010/11, and 2012/13, described below), 46.5% (case 1) of them have none of the SFM practices applied while 39.9% have only one of the three practices applied: 7.8% for the use of inorganic fertilizer only (case 2), 6.6% for the use of organic fertilizer only (case 3), and 25.5% for intercropping maize with legumes (case 4). On the contrary, relatively few maize plots (13.6%) have two or more SFM practices applied (cases 5, 6, 7, and 8). Table 2.1 also shows the four SI groups at the plot-level used in this study: the "Sustainable" group accounts for 37.1% of all maize plots while the "Intensification" (7.8%) and the "SI" (8.7%) groups are much less prevalent. Among the packages included in the "SI" group, the joint use of inorganic fertilizer and at least maize-legume intercropping is the dominant case (6.8% of all maize plots), while combined use of inorganic fertilizer and at least organic fertilizer is less common.

Since some households have multiple maize plots that might be managed in different ways, we generate a household-level SI category variable and use it to estimate the effects of the household's SFM strategy on household-level food access and other outcome variables. For the household level SI category variable, we compute the maize areas cultivated by the household under each SI category and then select as the household's SI category the category with the largest area. As shown in Table 2.1, the plot- and HH-level prevalences of the various SI categories are very similar. This is due to the following reasons: (i) about 65% of sample households in this study have only one maize plot, and (2) households with multiple maize plots have a tendency to use the same set of practices on all maize plots. Overall, 87% of the maize plots owned by our sample households fall in the same SI group at the plot and household levels.

Table 2.1: SI categories and prevalence on maize plots and among maize-growing households in Tanzania

Case	Inorganic fertilizer	Organic fertilizer	Maize-legume intercropping	Number of maize plots (%)	SI category	Plot level (%)	HH level (%)
1				2,519 (46.5)	Non-adoption	46.5	44.4
2	√			422 (7.8)	Intensification	7.8	6.6
3		√		358 (6.6)	Sustainable	37.1	39.5
4			√	1,384 (25.5)			
5		√	√	267 (4.9)			
6	√	√		102 (1.9)	SI	8.7	9.4
7	√		√	296 (5.5)			
8	√	√	√	71 (1.3)			
Use of inorganic fertilizer						15.4	16.1
Use of organic fertilizer						14.2	18.1
Use of maize-legume intercropping						38.2	46.6

Notes: Figures in the plot level column are based on all maize plots (N=5,419) completed harvesting by rural households pooled across the three waves of the TNPS (2008/09, 2010/11, and 2012/13). Figures in the HH level column are based on the total number of maize growers (N=3,641) in rural areas across these surveys. Legume crops for maize-legume intercropping are beans, soybeans, groundnuts, cowpeas, pigeon peas, chickpeas, field peas, green grams, bambara nuts, and fiwi.

2.3 Empirical strategy

In this section, we outline the econometric approaches used in this study. To empirically estimate the impacts of a household's use of a given set of agricultural practices based on observational data, a key challenge is to control for potential selection bias, where farmers often self-select into use or non-use of a given technology or combination of technologies. In the context of this study, selection bias occurs if unobserved characteristics influencing a household's decision on which set of SFM practices to use are correlated with the outcome variables considered here. If the selection bias is not adequately addressed, then econometric estimates are biased and inconsistent. One frequently used method to control for selection bias is propensity score matching; however, this approach only controls for selection on observable characteristics (Smith and Todd, 2005). Selection may also be related to unobservable factors. In order to address selection bias issues originating from observed *and* unobserved heterogeneity, we use an MESR approach following Kassie et al. (2018) and Khonje et al. (2018). The MESR framework involves a two-stage estimation procedure. In the first stage, a farmer's decision of which set of SFM practices to use (i.e., their SI category) is estimated in a multinomial logit selection (MNLS) model accounting for unobserved heterogeneity, and an inverse Mills ratio (IMR) is generated for each SI category. These are referred to as selection correction terms. In the second stage, the impacts of using each set of practices on a given outcome variable are estimated using ordinary least squares (OLS) with the IMRs included as additional covariates to capture selection bias arising from time-varying unobserved heterogeneity (Kassie et al. 2018). Other empirical studies that have applied the MESR model include Di Falco and Veronesi (2013), Teklewold et al. (2013), Kassie et al. (2015, 2018), and Khonje et al. (2018), among others.

In addition, we combine the MESR model with CRE techniques to further control for time-invariant unobserved household-level heterogeneity. To implement this approach, the means of time-varying covariates are included as additional regressors in both the first and the second stages (Wooldridge, 2010).

2.3.1 CRE-MNLS model

In the first stage, a farmer's decision of which SI category to be in is modeled in a random utility framework. Following Kassie et al. (2018) and Khonje et al. (2018), consider the following latent variable (U_{jit}^{*}) below that specifies a maize grower *i*'s utility from choosing strategy *j* (i.e., "Non-adoption" as a reference category ($j = 1$); "Intensification" ($j = 2$); "Sustainable" ($j = 3$); and "SI" ($j = 4$) in this study) at time *t* over all other alternative strategies, *m*:

$$U_{jit}^{*} = \boldsymbol{\alpha}_j \boldsymbol{X}_{jit} + \boldsymbol{\mu}_j \overline{\boldsymbol{X}}_{ji} + \varepsilon_{jit}, \tag{1}$$

where $\boldsymbol{X}_{jit}$ is a vector of observed exogenous covariates that represent household head characteristics, household endowments of physical, human, and social capital, agricultural extension and access to information and market services, shocks and other constraints, and input and expected output prices (described in 2.4.2 and Table 2A.1); $\overline{\boldsymbol{X}}_{ji}$ are the time-averages of these covariates to control for time-invariant household-level unobserved heterogeneity; ε_{jit} is time-varying unobserved characteristics; and $\boldsymbol{\alpha}_j$ and $\boldsymbol{\mu}_j$ are vectors of parameters to be estimated, respectively.

Farmer *i*'s utility is not directly observed but we do observe their SI category decision (strategy). It is assumed that farmer *i* will choose strategy *j* if strategy *j* provides greater utility than any other strategy $m \neq j$ (equation (2)):

$$U = \begin{cases} 1 \; if \; U_{jit}^* > \max_{m \neq 1}(U_{mit}^*) \text{ or } \eta_{1it} < 0 \\ \vdots \\ J \; if \; U_{jit}^* > \max_{m \neq J}(U_{mit}^*) \text{ or } \eta_{Jit} < 0 \end{cases} \qquad \text{for all } m \neq j, \tag{2}$$

where $\eta_{jit} = \max_{m \neq j}(U_{mit}^* - U_{jit}^*) < 0$.

Under the assumption that the ε_{jit} are independently and identically Gumbel-distributed, the probability that farmer *i* at time *t* will choose SI category *j* can be specified by a CRE-MNLS model as follows (McFadden, 1973):

$$P_{jit} = \Pr\left(\eta_{jit} < 0 \middle| \boldsymbol{X}_{jit}, \overline{\boldsymbol{X}}_{ji}\right) = \frac{\exp(\boldsymbol{\alpha}_j \boldsymbol{X}_{jit} + \boldsymbol{\mu}_j \overline{\boldsymbol{X}}_{ji})}{\sum_{m \neq 1}^{J} \exp(\boldsymbol{\alpha}_m \boldsymbol{X}_{mit} + \boldsymbol{\mu}_m \overline{\boldsymbol{X}}_{mi})}, \tag{3}$$

2.3.2 CRE-MESR model

In the second stage of the CRE-MESR model, we investigate the impacts of each strategy on a household's productivity on and net crop income from its maize plots as well as its food access (described in Section 2.4.2 below), controlling for the endogenous nature of the household's decision. The model in our study implies that households face a total of four regimes (i.e., $j = 1, 2, 3, 4$). The outcome equation for each regime is specified as:

$$\begin{cases} \text{Regime 1: } y_{1it} = \boldsymbol{\beta}_1 \boldsymbol{Z}_{1it} + \boldsymbol{\theta}_1 \overline{\boldsymbol{Z}}_{1i} + u_{1it} & \text{if } U = 1 \\ \vdots \\ \text{Regime } J\text{: } y_{Jit} = \boldsymbol{\beta}_J \boldsymbol{Z}_{Jit} + \boldsymbol{\theta}_J \overline{\boldsymbol{Z}}_{Ji} + u_{Jit} & \text{if } U = J, \end{cases} \qquad j = 1, 2, 3, 4 \tag{4}$$

where y_{jit} is the value of a given outcome variables for household *i* in regime *j* at time *t*; $\boldsymbol{Z}$ and $\overline{\boldsymbol{Z}}$ are vectors of explanatory variables and their household time-averages, respectively; and the error terms (u's) are distributed with $\mathrm{E}\left(u_{jit} \middle| \boldsymbol{X}, \overline{\boldsymbol{X}}, \boldsymbol{Z}, \overline{\boldsymbol{Z}}\right) = 0$ and $\mathrm{var}\left(u_{jit} \middle| \boldsymbol{X}, \overline{\boldsymbol{X}}, \boldsymbol{Z}, \overline{\boldsymbol{Z}}\right) = \sigma_j^2$. The outcome equation for each regime is estimated separately via OLS. However, if the error terms of the CRE-MNLS model (ε in equation (1)) are correlated with the error terms u of the outcome equation, the expected values of u conditional on the sample selection are non-zero, and then OLS estimates of equation (4) will be inconsistent. To address this potential inconsistency, selection correction terms for the alternative choices are included in equation (4), which takes into account the correlation between the ε's and the u's (Bourguignon et al. 2007). Per Bourguignon et al. (2007), consistent estimates of β and θ in the outcome equations (equation (4)) can be obtained via estimation of the following CRE-MESR models:

$$\begin{cases} \text{Regime 1: } y_{1it} = \boldsymbol{\beta}_1 \boldsymbol{Z}_{1it} + \boldsymbol{\delta}_1 \hat{\boldsymbol{\lambda}}_{1it} + \boldsymbol{\theta}_1 \overline{\boldsymbol{Z}}_{1i} + e_{1it} \quad \text{if } U = 1 \\ \quad \vdots \\ \text{Regime } J\text{: } y_{Jit} = \boldsymbol{\beta}_J \boldsymbol{Z}_{Jit} + \boldsymbol{\delta}_J \hat{\boldsymbol{\lambda}}_{Jit} + \boldsymbol{\theta}_J \overline{\boldsymbol{Z}}_{Ji} + e_{Jit} \quad \text{if } U = J, \end{cases} \qquad j = 1, 2, 3, 4 \tag{5}$$

In equation (5), e_{jit} is the error term, the expected value of which is zero; δ denotes the covariance between the ε's and u's; and $\hat{\lambda}$ is the estimated IMR, computed as follows:

$$\hat{\lambda}_{ji} = \sum_{m \neq j}^{J} \hat{\rho}_j \left[\frac{\hat{P}_{mi} \ln(\hat{P}_{mi})}{1 - \hat{P}_{mi}} + \ln(\hat{P}_{ji}) \right], \tag{6}$$

where $\hat{\rho}$ is the correlation coefficient between the $\hat{\varepsilon}$'s and the $\hat{u}$'s. $J - 1$ selection correction terms are included in the outcome equation, one for each adoption regime. Standard errors in equation (5) are bootstrapped to account for the two-stage estimation procedure (Di Falco and Veronesi, 2013).

For the model to be identified, it is critical to use selection instruments as exclusion restrictions in addition to selection terms automatically generated by the selection model of adoption (Di Falco and Veronesi, 2013). Following Kim et al. (in press), this study considers six candidate instrumental variables (IVs) that may directly influence a household's decision of which set of SFM practices to use but not their food access and other outcome variables. The candidate IVs are: the proportion of other households in the household's ward (i.e., excluding the household itself) (i) that received advice on agricultural production, (ii) that used inorganic fertilizer, (iii) that used organic fertilizer, and (iv) that used maize-legume intercropping; (v) electoral threat at the district level; and (vi) the number of National Agricultural Input Voucher Scheme (NAIVS) subsidized fertilizer vouchers distributed to the household's region.[26] The first four IVs are associated with access to information on and the potential for social learning about the three SFM practices considered in this study.[27] For IVs (v) and (vi), a household's adoption strategies, especially the sole use and/or combinations of inorganic fertilizer and other practices, could be influenced by subsidized fertilizer vouchers obtained from the Tanzanian government input subsidy program. However, a household's receipt of the vouchers is likely to be endogenous, so we instead use (v) and (vi) that are likely to affect a household's receipt of such vouchers but are exogenous to an individual household. The district-level electoral threat IV, defined as in Chang (2005), is the proportion of votes won in the most recent presidential election by the runner-up candidate divided by the proportion of votes won by the ultimately winning candidate. Several recent studies have used measures of electoral outcomes as an IV for household receipt of subsidized fertilizer because the spatial allocation of subsidized inputs in SSA countries, including Tanzania, may be connected to voting patterns during the most recent election (Mather and Minde, 2016; Mason et al., 2017; Mather and Jayne, 2018). Using constituency-level data from the 2005 and 2010 Tanzania presidential elections, this study generates the district-level electoral threat variable by aggregating up the vote totals to the district-level. For IV (vi), Tanzania's input subsidy program (NAIVS) was geographically concentrated on the areas that are the most suitable for maize and rice production. We thus

[26] TNPS includes total 26 regions, where each region is subdivided into districts. The districts are further divided into wards, where a ward is an administrative structure for one single town or portion of a bigger town.

[27] In recent studies on agricultural technology adoption decisions and their impacts (Kassie et al. 2015; Di Falco and Veroneisi 2013; Khonje et al. 2018), similar variables representing better access to information on modern agricultural technologies (e.g., distance to extension office, respondent's kinship network, and government extension, etc.) have been used as selection instruments.

include the number of vouchers for inorganic fertilizer allocated to the household's region per the World Bank (2014).

Of these six candidate IVs, we only include in a given first-stage regression the IVs that pass a simple falsification test. To be a valid selection instrument, it affects the household's SI category decision, but does not directly affect the outcome variable (Di Falco et al. 2011; Kassie et al. 2018). We conduct the falsification test following Khonje et al. (2018) and Kassie et al. (2018): the six candidate IVs are tested to determine if they are statistically significant in the CRE-pooled OLS model of each SI category; we then drop the IVs that are significantly correlated with a given outcome variable.

2.3.3 Estimation of average treatment effects on the treated (ATT)

The CRE-MESR framework above can be used to compute the average treatment effects on the treated (ATT) by comparing the expected outcomes of users ("adoption" below) and non-users ("non-adopters" below) of each SI strategy in actual and counterfactual scenarios. These actual and counterfactual scenarios can be specified as follow:

Adopters with adoption (actual),

$$E\left(y_{jit} \middle| U = j, \boldsymbol{Z}_{jit}, \overline{\boldsymbol{Z}}_{ji}, \hat{\boldsymbol{\lambda}}_{jit}\right) = \boldsymbol{\beta}_j \boldsymbol{Z}_{jit} + \boldsymbol{\delta}_j \hat{\boldsymbol{\lambda}}_{jit} + \boldsymbol{\theta}_j \overline{\boldsymbol{Z}}_{ji}. \tag{7}$$

Nonadopter without adoption (actual),

$$E\left(y_{jit} \middle| U = 1, \boldsymbol{Z}_{1it}, \overline{\boldsymbol{Z}}_{1i}, \hat{\boldsymbol{\lambda}}_{1it}\right) = \boldsymbol{\beta}_1 \boldsymbol{Z}_{1it} + \boldsymbol{\delta}_1 \hat{\boldsymbol{\lambda}}_{1it} + \boldsymbol{\theta}_1 \overline{\boldsymbol{Z}}_{1i}. \tag{8}$$

Adopters had they decided not to adopt (counterfactual),

$$E\left(y_{1it} \middle| U = j, \boldsymbol{Z}_{jit}, \overline{\boldsymbol{Z}}_{ji}, \hat{\boldsymbol{\lambda}}_{jit}\right) = \boldsymbol{\beta}_1 \boldsymbol{Z}_{jit} + \boldsymbol{\delta}_1 \hat{\boldsymbol{\lambda}}_{jit} + \boldsymbol{\theta}_1 \overline{\boldsymbol{Z}}_{ji}. \tag{9}$$

Nonadopter had they decided to adopt (counterfactual),

$$E\left(y_{jit} \middle| U = 1, \boldsymbol{Z}_{1it}, \overline{\boldsymbol{Z}}_{1i}, \hat{\boldsymbol{\lambda}}_{1it}\right) = \boldsymbol{\beta}_j \boldsymbol{Z}_{1it} + \boldsymbol{\delta}_j \hat{\boldsymbol{\lambda}}_{1it} + \boldsymbol{\theta}_j \overline{\boldsymbol{Z}}_{1i}. \tag{10}$$

Equations (7) and (8) denote for adopters and non-adopters, respectively, the expected values of a given outcome variable that are actually revealed in the sample while equations (9) and (10) refer to their counterfactuals (Kassie et al. 2018). For example, the counterfactual scenario described in equation (9) is defined as the outcome of adopters that would have been obtained if the coefficients on their explanatory variables ($\boldsymbol{Z}_{jit}, \overline{\boldsymbol{Z}}_{ji},$ and $\hat{\boldsymbol{\lambda}}_{jit}$) had been the same as the coefficients on the explanatory variables of the nonadopters, and *vice versa* (Ibid.). After estimating the CRE-MESR model, these conditional expectations are used to derive the ATT, which is defined as the difference between equations (7) and (9):[28]

$$ATT = E\left(y_{jit} \middle| U = j, \boldsymbol{Z}_{jit}, \overline{\boldsymbol{Z}}_{ji}, \hat{\boldsymbol{\lambda}}_{jit}\right) - E\left(y_{1it} \middle| U = j, \boldsymbol{Z}_{jit}, \overline{\boldsymbol{Z}}_{ji}, \hat{\boldsymbol{\lambda}}_{jit}\right)$$

$$= (\boldsymbol{\beta}_j - \boldsymbol{\beta}_1)\boldsymbol{Z}_{jit} + (\boldsymbol{\delta}_j - \boldsymbol{\delta}_1)\hat{\boldsymbol{\lambda}}_{jit} + (\boldsymbol{\theta}_j - \boldsymbol{\theta}_1)\overline{\boldsymbol{Z}}_{ji}. \quad (11)$$

The first term in equation (11) indicates the expected change in the mean of the outcome variable if the characteristics of adopters had been the same as nonadopters. The second term ($\hat{\boldsymbol{\lambda}}_{jit}$) in equation (9) along with the CRE approach ($\overline{\boldsymbol{Z}}_{ji}$) corrects for selection bias and endogeneity caused by unobserved heterogeneity.

[28] We also estimate the average treatment effects on the untreated (ATU), calculated as the difference between equations (8) and (10). These results are presented in Table 2A.16 of the Appendix.

2.4 Data and key outcome variables

2.4.1 Data

This study primarily uses the 2008/09, 2010/11, and 2012/13 TNPS data.[29] The TNPS is part of the World Bank's Living Standards Measurement Study-Integrated Surveys on Agriculture (LSMS-ISA) project, which was implemented by the TNBS with support from the World Bank. The topics covered in the survey include agricultural production, off-farm activities, consumption expenditure, and socioeconomic characteristics, among others. The TNPS was based on a stratified, multi-stage cluster sample design; the strata were Dar es Salaam, other urban areas and rural areas in mainland Tanzania, and Zanzibar. Clusters, the primary sampling units, were randomly selected from within each stratum with the probability of selection proportional to their population size. Then, eight households were randomly selected from each cluster.[30] The TNPS baseline sample (2008/09 TNPS) comprises 409 clusters and 3,265 households. 97% of households in the first round were re-interviewed in the second round (2010/11 TNPS), and 96% of the households in the second round were re-interviewed in the third round (2012/13 TNPS), which gives very low attrition rates between survey rounds (TNBS 2014).

The analytical sample used for the empirical analysis consists of the unbalanced panel of maize-growing households who have completed harvesting on their maize plots: 3,641 total

[29] Data for TNPS 2014/15 (i.e., the fourth wave of the survey) is now publicly available. However, the sample in the fourth wave of the survey was entirely refreshed for all future rounds, where only 860 households corresponding to 68 clusters were re-interviewed from the TNPS 2012/13. Thus, this study uses only the first three rounds of the survey for analysis.

[30] The unit for clusters is census enumeration areas (EAs) in urban areas (as defined in the 2002 Population and Housing Census) and villages in rural areas.

household observations (967 observations in 2008/09, 1,176 in 2010/11, and 1,498 in 2012/13). A slightly different analytical sample is used for the FCS outcome variable.[31]

The TNPS data also include various geospatial variables from other sources such as rainfall data and soil nutrient availability data, which were merged at the household level.[32] Among these, we use household distance to the nearest main road, town, and market.[33]

In addition to the TNPS, there are three additional sets of variables derived from other data sources that are used for the empirical analysis: (i) monthly wholesale price data for maize and rice from the Agricultural Market Information System (AMIS) of the Tanzania Ministry of Industry and Trade (MIT);[34] (ii) the number of subsidized inorganic fertilizer vouchers distributed to regions from World Bank (2014); and (iii) constituency-level data for the 2005 and 2010 presidential elections from the Electoral Commission of Tanzania.[35]

2.4.2 Outcome variables and explanatory variables

To analyze the effects of various SI categories on households' income, productivity, and food access, we use seven outcome variables: (i) net crop income from maize plots (henceforth simply "net crop income" for brevity); (ii) net crop income per acre; (iii) net crop income per adult equivalent; (iv) crop productivity (per unit of land) on maize plots (henceforth simply "crop productivity" for brevity); (v) household's consumption expenditure on food and beverages per

[31] In the TNPS data used in this study, consumption frequency is captured in the second and third waves (TNPS 2010/11 and 2012/13) but not in the first (2008/09). Therefore, for the FCS outcome variable, the analytical sample involves the balanced maize-growing households that were interviewed in both the second and third waves: 1,622 total household observations (811 observations in each wave).
[32] The source of the rainfall data is the National Oceanic and Atmospheric Administration-Climate Prediction Center and that of the soil nutrient availability data is the Harmonized World Soil Database.
[33] Each distance variable is from a different source. Distance to main road is from OpenStreetMaps, distance to town is from City Population, and distance to main market is from Famine Early Warning Systems Network.
[34] These data are collected weekly from twenty wholesale markets in Tanzania. There are six regions (out of 26 in the TNPS) that are not covered by these data. For these regions, an average wholesale price of adjacent regions' markets is used for the empirical analysis.
[35] The author thanks Dr. David Mather for sharing these data.

adult equivalent; (vi) modified household dietary diversity score (HDDS); and (vii) food consumption score (FCS). The first four outcome variables ((i) to (iv)) are used as measures for the impact pathways through which each SI category could affect households' food access and the other three outcome variables ((v) to (vii)) are used as measures of the household's food access. We discuss the construction of each of these outcome variables in turn.

For net crop income, note that many Tanzanian smallholders' maize plots include intercrops with legumes and/or other crops. To take into account income from all crops on a given maize plot, we compute net crop income at the household level as follows:

$$Net\ crop\ income_i = \sum_m \left[\sum_j Q_{ijm}P_j - \sum_h x_{ihm} - \sum_j s_{ijm}\right], \quad (12)$$

where Q_{ijm} is the quantity (kg) of crop *j* harvested by household *i*, P_j is the regional median market price of crop *j* in TZS/kg, x_{ihm} is the cost of input *h* (i.e., land rental, purchased inorganic fertilizer and organic fertilizer, and hired labor) used by household *i*, s_{ijm} is the cost of seed purchased to produce crop *j*, and *m* indexes the maize plots cultivated by household *i*. Using net crop income per equation (12), we then generate net crop income per acre of maize plots and net crop income per adult equivalent by dividing net crop income by the total acreage of maize plots cultivated by household *i* and by the number of adult equivalents in household *i*, respectively. (Acreage of maize plots refers to the acreage of plots that contain at least some maize.) Given that food prices increase over time and inflation is considerably higher in rural areas than urban areas (TNBS, 2014), real 2013 prices for P_j, *x*, and *s* are used to generate the net crop income-related variables.

For the crop productivity outcome variable, we calculate an output index following Liu and Myers (2009) and then divide it by the household's total maize plot acreage (L_i) including the area of intercropped plots as follows:

$$Productivity_i = \left[\frac{\sum_m \sum_j Q_{ijm} P_j}{P_1}\right] / L_i, \quad (11)$$

where P_1 is the regional median price of maize and the other variables are as defined above.

For the food/beverage consumption expenditure, modified HDDS, and FCS outcome variables, we draw on the household food consumption data that were collected in the TNPS. These data are based on a seven-day recall period prior to the survey and cover over 50 food/beverage items. HDDS and FCS are both indicators of the food access component of household food security (Jones et al., 2013; Leroy et al., 2015). The modified HDDS is calculated as a count over 12 food groups (cereals, roots and tubers, vegetables, fruits, meat and poultry, eggs, fish and seafood, pulses/legumes/nuts, milk and milk products, oils and fats, sugar and honey, and miscellaneous) consumed during the seven-day reference period; this variable is thus a count variable with values ranging from zero to 12.[36] The FCS takes on values ranging from zero to 112 as it is calculated as the consumption frequency of nine food groups (main staples, pulses, vegetables, fruit, meat and fish, milk, sugar, oil, and condiments) during the last seven days multiplied by a group-specific weight and then summed up (World Food Programme, 2008). Our third indicator of household food access, consumption expenditure on food and beverages per adult equivalent, is provided in each round of the TNPS. All sources of consumption are included (purchases, own production, gifts received, and goods bartered in) and the variable only includes the actual consumption of the household over the previous seven days.[37]

[36] The standard HDDS is calculated based on food consumption during the previous 24 hours (Swindale and Bilinsky, 2006). However, such data are not available in the TNPS so we calculate a modified HDDS based on food consumption during the previous 7 days.
[37] For all of these outcome variables except for the modified HDDS and the FCS, a one percent winsorization in each tail was used to prevent the results from being heavily influenced by outliers.

Descriptive statistics for the seven outcome variables and control variables used in the analysis are presented in Table 2.2.[38] Summary statistics on the six candidate instrumental variables are also included in this table.

The control variables were selected based on a careful review of the literature associated with technology adoption and its impacts on household income, productivity, and food security in African countries (e.g., Khonje et al., 2018; Kassie et al., 2015a, b; Kassie et al., 2018; Teklewold et al., 2013; Manda et al., 2016). These variables include characteristics of the household head (age, gender, and education); household endowments of physical, human, and social capital (family labor defined as the number of adults (15-64 years old) per acre of cultivated land, total cultivated land, off-farm income, real value of farm assets (1,000 TZS), livestock ownership, access to credit, membership in a Savings and Credits Cooperatives Society (SACCOS); agricultural extension and access to information, markets, and services (household-level receipt of extension advice from government/NGO, household distance to main road/town/market, presence of cooperatives/input supplier within the village); shocks and other constraints (drought/flood and crop disease/pest shocks in the past two years, total rainfall, soil nutrient constraint);[39] and input and proxies for expected output prices (inorganic fertilizer price

[38] A detailed description of the variables and summary statistics by SI category are presented in Appendix Table 2A.1. In addition, note that some of the control variables in our models are time-invariant for almost all households (e.g., education of the household head, distance to the nearest market, and a binary variable for livestock ownership). Thus, we excluded the time-averages of these variables from both stages of the CRE-MESR model.

[39] According to the Harmonized World Soil Database, soil nutrients are estimated based on soil texture, soil organic carbon, soil pH, and total exchangeable bases of the topsoil (0-30 cm) and the subsoil (30-100 cm). In general, the moderate constraint of the soil nutrient availability is rated between 60% and 80% of the plant growth potential while the severe and very severe constraints are rated between 40% and 60%, and less than 40% of the growth plant potential, respectively. A challenge associated with this database is the coarse resolution relative to the variability of these properties so although this is the only available soil data that could be associated with the TNPS, the mismatch in scale must be acknowledged.

at district level, lagged prices of maize and rice at the region level, bean and groundnut price at region level).[40]

[40] The average price of inorganic fertilizer per kilogram at district level is included as the major relevant input price in this study. Using data from AMIS-MIT, this study includes the average wholesale prices of maize and rice during the post-harvest period (from July to September) in the previous year as proxies for the households' expected prices of maize and rice. However, such data are not available for beans and groundnuts, so we instead use the average producer prices of these crops at region level in each TNPS survey round as a proxy for the expected legume prices. All of these input and output prices are deflated by the CPI (2013=100).

Table 2.2: Descriptive statistics by survey round

	TNPS 2008/09		TNPS 2010/11		TNPS 2012/13		Full sample	
Variables	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Outcome variables								
Net crop income (1000 TZS)	315.41	544.52	317.29	549.28	382.09	614.87	343.45	576.72
Net crop income per acre	98.32	113.69	93.54	106.01	106.34	119.09	100.08	113.67
Net crop income per adult equivalent	79.85	126.15	74.83	119.58	84.44	118.76	80.12	121.07
Crop productivity	408.55	434.83	394.25	417.22	389.39	414.54	396.05	420.84
Food expenditure per adult equivalent	388.43	218.54	423.40	255.95	578.99	334.10	478.12	294.99
Modified HDDS	7.69	2.03	8.08	1.91	7.90	2.00	7.90	1.98
FCS	-	-	50.87	16.50	50.68	17.73	50.78	17.12
Explanatory variables								
Male-headed HH (yes = 1)	0.78	0.42	0.77	0.42	0.78	0.41	0.78	0.42
Age of HH head (years)	47.27	15.95	48.13	15.62	48.57	16.12	48.08	15.92
Education of HH head (years)	4.52	3.32	4.52	3.46	4.72	3.46	4.60	3.42
Family labor (number of adults per acre)	0.99	1.22	1.15	2.00	1.15	1.79	1.11	1.73
Total cultivated land (acres)	6.32	22.75	5.48	8.27	6.93	13.78	6.30	15.42
Off-farm income (yes = 1)	0.54	0.50	0.62	0.49	0.64	0.48	0.61	0.49
Farm assets (1,000 TZS)	1,296.49	7,144.48	1,296.32	7,802.01	1,738.75	7,407.92	1,478.39	7,470.75
Livestock ownership (yes = 1)	0.45	0.50	0.45	0.50	0.42	0.49	0.44	0.50
Access to credit (yes = 1)	0.06	0.23	0.07	0.25	0.10	0.30	0.08	0.27
Membership (SACCOS) (yes = 1)	0.04	0.19	0.05	0.22	0.04	0.19	0.04	0.20
Extension from gov't/NGO (yes = 1)	0.16	0.36	0.08	0.28	0.06	0.24	0.09	0.29
Distance to main road (km)	21.45	22.17	23.18	23.55	22.04	22.29	22.25	22.68
Distance to town (km)	56.25	37.14	56.71	38.83	57.66	38.87	56.98	38.40
Distance to main market (km)	85.13	52.53	85.06	54.00	87.09	54.14	85.91	53.66

Table 2.2 (cont'd)

Variables	TNPS 2008/09 Mean	TNPS 2008/09 SD	TNPS 2010/11 Mean	TNPS 2010/11 SD	TNPS 2012/13 Mean	TNPS 2012/13 SD	Full sample Mean	Full sample SD
Explanatory variables (cont'd)								
Cooperatives (yes = 1)	0.45	0.50	0.42	0.49	0.37	0.48	0.41	0.49
Input supplier (yes = 1)	0.33	0.47	0.36	0.48	0.40	0.49	0.37	0.48
Drought/Flood (yes = 1)	0.10	0.31	0.13	0.34	0.11	0.31	0.11	0.32
Crop disease/Pests (yes = 1)	0.10	0.31	0.10	0.30	0.06	0.24	0.09	0.28
Total rainfall (mm)	756.16	307.13	817.15	296.25	825.24	246.11	804.28	281.29
Soil nutrient constraint (yes = 1)	0.60	0.49	0.63	0.48	0.64	0.48	0.63	0.48
Inorganic fertilizer price (TZS/kg)	1,765.72	712.48	1,426.31	758.01	1,504.83	889.20	1,548.76	814.56
Lagged price of maize (TZS/kg)	353.56	75.44	517.61	89.34	527.35	114.54	478.05	122.91
Lagged price of rice (TZS/kg)	1,089.67	162.80	1,484.96	182.41	1,524.18	146.03	1,396.11	246.56
Bean price (TZS/kg)	1,579.56	241.94	1,615.55	125.51	1,523.58	126.28	1,568.15	169.58
Groundnut price (TZS/kg)	1,685.18	275.80	2,368.40	344.96	1,986.39	301.09	2,029.78	406.51
Year dummy (2010/11)	0.00	0.00	1.00	0.00	0.00	0.00	0.32	0.47
Year dummy (2012/13)	0.00	0.00	0.00	0.00	1.00	0.00	0.41	0.49
T2 dummy	0.28	0.45	0.38	0.49	0.27	0.44	0.31	0.46
T3 dummy	0.54	0.50	0.44	0.50	0.35	0.48	0.43	0.49
Instrumental variables								
Electoral threat	0.18	0.71	0.20	0.69	0.36	0.34	0.26	0.59
Number of subsidized fertilizer vouchers	47,718	51,537	113,335	106,153	49,854	30,967	69,791	75,116
Proportion receiving agricultural advice	17.25	20.58	10.87	18.15	8.10	14.77	11.43	17.95
Proportion adopting inorganic fertilizer	17.14	28.39	20.22	31.61	17.15	29.86	18.14	30.08
Proportion adopting organic fertilizer	19.59	24.51	18.22	27.75	19.49	27.38	19.11	26.77
Proportion adopting maize-legume IC	45.06	31.89	40.62	31.12	40.96	34.34	41.94	32.73

Notes: TZS = Tanzanian Shillings. SD = standard deviation. IC = intercropping. T2 and T3 dummies are variables for frequency of the household across survey rounds.

2.5 Results and discussion

The primary objective of this study is to analyze the impacts of the use of practices in each SI category on household's crop income and productivity which could be the primary pathways to improve smallholder farmers' food access. At the same time, we examine whether the use of these practices indeed enhances household's food access. We therefore do not discuss the first stage regression results in detail beyond those related to the effects of the IVs on the household's choice of SI strategy. The first stage results are presented in Appendix Tables 2A.2-2A.8.[41] The results from a joint significance test of the excluded IVs in these tables confirm that the IVs are jointly significant at the 1% level. Moreover, the IVs used in each first stage regression pass the simple falsification test, suggesting that they do not directly affect the household's net crop income-, crop productivity-, or food access-related outcome variables. (See Tables 2A.9-2A.15 for the simple falsification test results). The full CRE-MESR regression results for the second stage are reported in Appendix Tables 2A.9-2A.15. In some of the outcome equations, the IMRs ($\hat{\lambda}$s) and the mean of time varying variables are statistically significant, implying the presence of sample selection in SI category choice (Kassie et al. 2018). The predicted outcomes from the CRE-MESR models are used to estimate adoption effects on household income, productivity, and food access.

Unconditional average effects of various SI category choices on each outcome variable are reported in Appendix Table 2A.17, which are calculated based on the actual and counterfactual distributions. The results show that for all SI categories except for "Intensification" for the FCS outcome, use of practices in each SI category is positively

[41] Since the coefficients reported in Appendix Table 2A.2-2A.8 are the log-odds of each respective SI category, we need to calculate marginal effects to make inferences based on actual probabilities. The marginal effects for each outcome variable are reported in Appendix Table 2A.18-2A.24.

associated with all of the households' crop income-, productivity-, and food access-related outcomes relative to non-adoption, on average. However, these results could be misleading because selection bias from both observed and unobserved factors that may affect the outcome variables has not been addressed in these results (Khonje et al., 2018). Below, we therefore focus on the average effects of use of practices in the various SI categories after controlling for selection bias.

2.5.1 Impacts of using practices in each SI category on household income and productivity

Table 2.3 presents the ATT of the use of practices in the various SI categories on households' net crop income and crop productivity, which is calculated as the difference between column (1) and (2): for example, we compare a household's expected net crop income (1,000 TZS) from their maize plots based on the actual combination of SFM practices they used, and the counterfactual that they used none of the practices (i.e., columns (1) and (2), respectively). In all cases, households who use a given set of SFM practices would have obtained less desirable outcomes if they had not done so; all ATTs are positive and statistically significant at the 1% level. Of the three SI categories (i.e., "Intensification", "Sustainable", and "SI"), the smallest positive effects on households' income and productivity outcomes are obtained from the "Sustainable" group. We also find that for all outcome variables, these positive effects of the "Sustainable" group are statistically different from "Intensification" and "SI" at or below the 5% level. On the other hand, for both net crop income and net crop income per adult equivalent, the greatest effects on the outcome variables are observed for the "SI" category and these effects are statistically different from the "Sustainable" and "Intensification" effects. More specifically, the use of practices in the "SI" category increases net crop income by 153.2% on average (ATT divided by average counterfactual net crop income) and net crop income per adult equivalent by 41.5%. For net crop income per acre and crop productivity, the effects of both “Intensification” and “SI” are larger than the effects of “Sustainable”, but the “Intensification” and “SI” effects are not statistically different from each other. Overall, these results indicate that farmers’ use of the practices in the “SI” category gives them higher average returns than use of only “Sustainable” practices in terms of all net crop income-related and productivity outcomes. Moreover, “SI” generates higher or at least similar returns for these outcomes relative to “Intensification”. This is consistent with evidence in the agronomic literature cited above and cited extensively in Kim et al. (in press) that there are synergistic or complementary effects when inorganic fertilizer and organic-based SFM practices are used together. For example, the use of organic fertilizer and/or maize-legume intercropping could improve soil quality through increases in SOM and soil pH level and then enhance crop yield response of applied inorganic fertilizer use, which could lead to increases in crop income and productivity. In addition, legume crops produced through the use of maize-legume intercropping among households in the “SI” group could help these farmers to further increase their crop income due to relatively higher market price per kilogram than maize price (if this higher price offsets potentially higher costs of production and lower legume yields per unit of land relative to maize). In addition, the finding that the “Sustainable” productivity effects are smaller than those of “Intensification” and “SI” is consistent with the use of maize-legume intercropping and organic fertilizer without inorganic fertilizer being unlikely to significantly increase crop yields in the short run.

The results in Table 2.3 are difficult to directly compare with findings in previous studies because each study considered different combinations of agricultural practices. However, our household crop income and productivity effects are consistent with the main findings that the combined use of practices potentially associated with SI provides higher maize yields and maize income relative to the use of other practices in Ethiopia (Kassie et al., 2018; Teklewold et al., 2013), and Zambia (Khonje et al. 2018). More specifically, Kassie et al. (2018) considered the combinations of inorganic fertilizer, an improved maize variety, and legume diversification (maize-legume intercropping or rotation) and found that the use of legume diversification jointly with at least one of the other two technologies substantially improve household maize yields compared to sole or combined use of the other practices. Similarly, the other two studies used combinations of an improved maize variety and at least one other practice (minimum tillage in Khonje et al. (2018) and maize-legume rotation and/or conservation tillage in Teklewold et al. (2013)). These latter studies' results suggest that the combined use of an improved maize variety and at least one of the other practices considered could deliver higher returns on household maize yields and/or maize income compared to any practice on its own.

Table 2.3: ATTs of using practices in each SI category on household net crop income and productivity

Outcome variables	SI category	Adoption status: Adopting ($j = 2, 3, 4$)	Nonadopting ($j = 1$)	ATT
		(1)	(2)	(3) = (1) – (2)
Net crop income (1,000 TZS) (N=3,641)	Intensification	441.40 (30.62)	232.45 (11.91)	208.95*** (28.99)
	Sustainable	365.17 (8.97)	283.45 (5.80)	81.72*** (5.08) SD††
	SI	549.53 (30.63)	217.02 (8.15)	332.51*** (28.27) SD†
Net crop income (1,000 TZS) per acre (N=3,641)	Intensification	116.52 (4.91)	76.36 (2.00)	40.16*** (4.65)
	Sustainable	108.15 (0.97)	80.89 (0.85)	27.26*** (0.79) SD††
	SI	114.75 (3.86)	81.09 (1.65)	33.66*** (3.97)
Net crop income (1,000 TZS) per adult equivalent (N=3,641)	Intensification	102.96 (6.30)	60.55 (2.00)	42.41*** (5.68)
	Sustainable	81.77 (1.16)	63.12 (0.86)	18.65*** (0.93) SD††
	SI	120.62 (6.08)	56.99 (1.55)	63.63*** (5.53) SD†
Crop productivity (N=3,641)	Intensification	633.22 (19.89)	346.86 (6.97)	286.36*** (18.31)
	Sustainable	384.47 (3.59)	286.10 (3.18)	98.37*** (2.90) SD††
	SI	652.78 (16.78)	346.82 (6.08)	305.96*** (14.91)

Notes: Standard errors in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. For each outcome variable, SD†† indicates that the "Sustainable" ATT is statistically different from both the "Intensification" and "SI" ATTs at or below the 5% level, while SD† indicates that the "SI" ATT is statistically different from the "Intensification" ATT.

2.5.2 Impacts of using practices in each SI category on household food access outcomes

The ATTs for outcomes representing household food access (modified HDDS, food expenditure per adult equivalent, and FCS) are reported in Table 2.4. One observation is that use of practices in both the "Sustainable" and "SI" categories increases food access relative to "Non-adoption" for all three outcome variables, but this is only the case for "Intensification" for the modified HDDS outcome.[42] Below, we discuss the results for each food access indicator in more detail.

For the modified HHDS outcome, we find that the use of practices in the "Intensification" and "SI" categories is associated with increases in a household's modified

[42] Relatedly, Snapp and Fisher (2015) find that a one-crop increase in the number of crops intercropped raises the HDDS and FCS.

HDDS of 6.5% and 9.2%, respectively; moreover, the “SI” ATT is statistically larger than the “Intensification” ATT. The “Sustainable” ATT is also statistically different from zero but at 0.6%, this effect is very small in magnitude relative to the effects of the other two categories (Table 2.4). These results are consistent with the positive effects of all three of these SI categories on net crop income and productivity in Table 2.3. They are also consistent with the findings in Table 2.3 that the “Intensification” and “SI” effects are consistently larger than the “Sustainable” effects, and that the “SI” effects are larger than the “Intensification” effects for two of the three net crop income-related outcomes in Table 2.3. Thus, improvements in HDDS as a result of “Intensification” and “SI” appear to be coming through both the crop income and productivity pathways; in addition, the relatively larger effects of “SI” compared to “Intensification” on HDDS appear to be mainly due to larger increases in net crop income as there is no statistically significant difference in the productivity ATTs for “SI” and “Intensification”. The inclusion of legumes via maize-legume intercropping in some of the sets of practices included in the “SI” category might also be contributing to the relatively larger effects of “SI” than “Intensification” on a household’s modified HDDS.

For the food expenditure per adult equivalent and FCS outcomes, we find that, relative to using none of the SFM practices studied here, use of packages in the “SI” group is associated with increases of 4.1% and 3.0% on average, respectively. However, in contrast to the HDDS results, the food expenditure per adult equivalent and FCS results suggest that use of “Sustainable” practices also substantially increases these outcomes (by 4.0% and 3.6% respectively) while “Intensification” has no statistically significant effect. In addition, the “SI” effect is not statistically larger than the “Sustainable” effect for food expenditure per adult equivalent and FCS.[43] Further research is needed to investigate what is driving the food expenditure results to be similar for "Sustainable" and "SI" and not statistically significant for "Intensification". However, a possible explanation for this pattern for the FCS results could be the inclusion of maize-legume intercropping in the "Sustainable" and "SI" categories but not in "Intensification". Recall that roughly 80% of the maize plots in the "Sustainable" and "SI" groups involve maize-legume intercropping (Table 2.1). If households consume some or all of the legumes they produce through maize-legume intercropping, this could considerably increase their FCS because pulses are highly weighted in the FCS.[44] Moreover, per Kim et al. (in press), maize-legume intercropping is the main way in which maize-growing households in rural Tanzania produce legumes (as opposed to growing legumes separately from maize). Furthermore, legume consumption among legume-producing households is two times greater than legume consumption among those who only purchase legumes (Stahley et al., 2012). For households in the "Intensification" group, focusing on maize production through the sole use of inorganic fertilizer may not be enough to substantially raise FCS. Finally, the positive and relatively large effects of "Sustainable" and "SI" on food expenditure per adult equivalent could also be contributing to these practices' positive effects on FCS – i.e., households may not just be producing more and more diverse foods which they then consume, they may be purchasing them as well.

The results here might also suggest that the positive effects of "SI" practices on child nutrition outcomes found by Kim et al. (in press) could be linked to increases in HDDS, FCS, and food expenditure.

[43] The ATTs of the "Sustainable" for both food expenditure per adult equivalent and FCS outcomes are not statistically different from those in the "SI" category.
[44] The weight of pulses is three which is the second highest among the nine food groups used to calculate the FCS. The food groups with the highest weight, four, are meat and fish, and milk items.

Table 2.4: ATTs of using practices in each SI category on household food access outcomes

Outcome variables	SI category	Adoption status		ATT
		Adopting	Nonadopting	
		$(j = 2, 3, 4)$	$(j = 1)$	
		(1)	(2)	(3) = (1) – (2)
Modified HDDS	Intensification	8.39 (0.07)	7.88 (0.05)	0.51*** (0.07)
(N=3,641)	Sustainable	7.87 (0.02)	7.82 (0.02)	0.05*** (0.01) SD††
	SI	8.67 (0.05)	7.89 (0.04)	0.78*** (0.04) SD†
Food expenditure (1,000 TZS)	Intensification	516.00 (11.94)	503.66 (8.05)	12.34 (10.33)
per adult equivalent	Sustainable	486.35 (2.71)	467.65 (3.22)	18.70*** (1.65)
(N=3,641)	SI	526.89 (9.80)	506.23 (6.08)	20.66*** (7.07)
FCS	Intensification	49.62 (0.88)	49.56 (0.57)	0.06 (0.80)
(N=1,622)	Sustainable	52.28 (0.32)	50.47 (0.35)	1.81*** (0.28) SD†
	SI	53.08 (0.99)	51.52 (0.50)	1.56** (0.81)

Notes: Standard errors in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. For each outcome variable, SD†† indicates that the "Sustainable" ATT is statistically different from both the "Intensification" and "SI" ATTs at or below the 5% level, while SD† indicates that the "SI" ATT is statistically different from the "Intensification" ATT.

Before concluding, it is important to note the limitations of the study. First, the data used here do not capture households' use of practices in the farming seasons between survey rounds or in years prior to the first survey. We therefore only capture the short-run effects of the various SFM practices studied here but the long-run effects could also be important. In addition, we measure farmers' plot-level SI category decisions using dummy variables that denoted whether a given SFM practice was applied or not without considering the intensity of application (e.g., the amount of inorganic fertilizer or organic fertilizer applied or the proportion of area covered by legume crops). This intensity of use could affect households' productivity and crop income as well as their food access outcomes. Future research with richer data (if available) to address these shortcomings would be worthwhile. We also used observational data and have relied on econometric methods (each with their own assumptions) to try to estimate causal effects;

however, we may not have fully addressed selection bias issues. Exploring how to examine similar research questions using a randomized-controlled trial would thus also be useful.

2.6 Conclusions and policy implications

Low agricultural productivity and food insecurity are major challenges in SSA, where agriculture is central to rural livelihoods. Sustainable intensification has received considerable attention as a possible means to address these challenges but there have been very few studies that have attempted to evaluate the relationship between SI and farm households' food security. Therefore, in this study, we estimate the effects of households' use of various combinations of SFM practices that could contribute to SI of maize production in Tanzania on rural maize-growing households' food access, an important dimension of food security. We also estimate the effects on their net crop income and productivity – the two primary pathways through which changes in SFM practices are likely to affect farm households' food access. To deal with potential selection bias originating from both observed and unobserved heterogeneity, we use CRE-MESR models to estimate these effects.

Our findings suggest that "Intensification" (use of inorganic fertilizer only), "Sustainable" practices (use of organic fertilizer and/or maize-legume intercropping but no inorganic fertilizer), and "SI" (use of inorganic fertilizer with at least one of the "Sustainable" practices) on maize plots all have positive effects on households' net crop income-related outcomes and crop productivity relative to use of none of the three SFM practices considered here. Importantly, use of practices in the "SI" category have consistently larger effects than "Sustainable" practices on these outcomes, and larger or similar effects on them compared to "Intensification". In terms of food access, all three sets of practices ("Intensification", “Sustainable”, and “SI”) raised a household’s modified HDDS, with the largest effects occurring for the “SI” group. Use of practices in the “SI” group also raised food expenditure per adult equivalent and households’ FCS more than “Intensification” and by a similar magnitude as “Sustainable” practices. Thus, across all the outcomes considered here, use of practices in the “SI” group either improves the outcomes more than or by similar magnitudes as “Sustainable” practices or “Intensification” alone. This, coupled with the findings of Kim et al. (in press) that use of practices in the “SI” group improves child nutrition outcomes among Tanzanian maize-growing households (but “Sustainable” practices and “Intensification” generally do not) suggests that there may be major food security and nutrition benefits (not to mention soil fertility and productivity benefits) to promoting joint use of inorganic fertilizer with complementary organic soil fertility practices. While further research is needed to determine how best to do this, our first stage regression results (Tables 2A.18-2A.24) suggest that improving education, access to agricultural extension services, and access to credit are key drivers of Tanzanian maize farmers’ decisions to jointly use these practices.

APPENDIX

Table 2A.1: Summary statistics by SI category

Variables	Variable description	Mean value of each SI category				Mean of all
		N	I	S	SI	
Outcome variables						
Net crop income	Real net crop income on maize plots (2013 = 100)	265.73	441.40	365.17	549.53	343.45
Net crop income per acre	Real net crop income per acre of maize plots (2013 = 100)	87.33	116.52	108.15	114.75	100.08
Net crop income per adult equivalent	Real net crop income per adult equivalent (2013 = 100)	66.64	102.96	81.77	120.62	80.12
Crop productivity	Crop productivity based on output index following Liu and Myers (2009)	316.54	633.22	384.47	652.78	396.05
Food expenditure per adult equivalent	Real food and beverage consumption expenditure	454.80	516.01	486.35	526.89	478.12
Modified HDDS	Modified household dietary diversity score (0-12)	7.68	8.40	7.88	8.67	7.90
FCS	Food consumption score (0–112)	49.14	49.62	52.28	53.08	50.78
Explanatory variables						
Male-headed HH	1 = yes if the household head is male	0.77	0.84	0.77	0.82	0.78
Age of HH head	Age of the household head (years)	47.38	44.81	49.45	47.91	48.08
Education of HH head	Highest grade completed by the household head (years)	4.30	6.13	4.38	5.91	4.60
Family labor	Number of adults (15-64 years old) per acre of cultivated land	1.10	0.99	1.15	1.06	1.11
Total cultivated land	Total land area cultivated (acres)	6.09	5.99	6.53	6.58	6.30
Off-farm income	1 = yes if the HH earned off-income in the past 12 months	0.59	0.69	0.62	0.62	0.61
Farm assets	Real total value of farm implements and machinery (1,000 TZS) owned in the past 12 months (2013=100)	1,085.97	1,094.78	2,183.51	639.02	1,478.39
Livestock ownership	1 = yes if the HH has livestock (cattle, goats, sheep, pigs, or donkeys)	0.34	0.44	0.51	0.58	0.44
Access to credit	1 = yes if the HH borrowed cash, goods, or services in the past 12 months	0.07	0.11	0.08	0.14	0.08
Membership (SACCOS)	1 = yes if the HH has a member of SACCOS	0.03	0.08	0.04	0.08	0.04
Extension from gov't/NGO	1 = yes if the HH received agricultural advice from government/NGO in the past 12 months	0.08	0.17	0.07	0.20	0.09

Table 2A.1 (cont'd)

Variables	Variable description	Mean value of each SI category N	I	S	SI	Mean of all
Explanatory variables						
Distance to main road	Household distance to main road (km)	24.57	17.06	22.05	15.85	22.25
Distance to town	Household distance to nearest town of > 20,000 population (km)	58.99	48.81	57.69	50.27	56.98
Distance to main market	Household distance to major market (km)	84.73	92.25	84.90	91.29	85.91
Cooperatives	1 = yes if farmers' cooperative present within the village	0.40	0.58	0.37	0.47	0.41
Input supplier	1 = yes if improved maize seed supplier present within the village	0.33	0.56	0.33	0.55	0.37
Drought/Flood	1 = yes if the HH was negatively affected by drought or flood in the past two years	0.12	0.07	0.12	0.05	0.11
Crop disease/Pests	1 = yes if the HH was negatively affected by crop diseases or pests for the past two years	0.08	0.07	0.09	0.08	0.09
Rainfall	12-month total rainfall (mm) in July-June	798.99	863.75	791.33	841.86	804.28
Soil nutrient constraint	1 = yes if soil nutrient availability constraint is moderate or (very) severe	0.61	0.70	0.61	0.73	0.63
Inorganic fertilizer price	Real inorganic fertilizer price at district level (TZS/kg) (2013=100)	1,549.92	1,419.75	1,615.28	1,354.87	1,548.76
Lagged price of maize	Real average price of maize from Jul. to Sep. in prior year (TZS/kg) (2013=100)	480.17	423.73	495.05	434.82	478.05
Lagged price of rice	Real average price of maize from Jul. to Sep. in prior year (TZS/kg) (2013=100)	1,402.55	1,365.56	1,398.24	1,378.28	1,396.11
Bean price	Real bean market price at region level (TZS/kg) (2013=100)	1,578.39	1,527.97	1,571.06	1,535.90	1,568.15
Groundnut price	Real groundnut market price at region level (TZS/kg) (2013=100)	2,008.68	2,057.88	2,037.31	2,077.84	2,029.78
Year dummy (2010/11)	1 = yes if the household is in TNPS 2010/11 sample	0.34	0.31	0.29	0.38	0.32
Year dummy (2012/13)	1 = yes if the household is in TNPS 2012/13 sample	0.38	0.46	0.44	0.39	0.41
T2 dummy	1 = yes if the household is observed twice in any of the three waves	0.32	0.27	0.30	0.29	0.31
T3 dummy	1 = yes if the household is observed in all three waves	0.41	0.58	0.38	0.57	0.43

Table 2A.1 (cont'd)

Variables	Variable description	Mean value of each SI category N	I	S	SI	Mean of all
Instrumental variables						
Electoral threat	Proportion of votes for the runner-up divided by the proportion of votes for the presidential winner	0.30	0.18	0.25	0.18	0.26
Number of subsidized fertilizer vouchers	Number of inorganic fertilizer (nitrogen) vouchers distributed to region	62,622	113,500	57,338	125,118	69,791
Proportion receiving agricultural advice	Proportion of other households in the ward that got advice on agricultural production	9.39	20.42	9.91	21.09	11.43
Proportion using inorganic fertilizer	Proportion of other households in the ward that use inorganic fertilizer	8.76	60.13	11.79	59.51	18.14
Proportion using organic fertilizer	Proportion of other households in the ward that use organic fertilizer	13.99	26.23	21.41	28.57	19.11
Proportion using maize-legume IC	Proportion of other households in the ward that use maize-legume intercropping	32.97	45.63	48.77	52.98	41.94

Notes: TZS = Tanzanian Shillings. SD = standard deviation. IC = intercropping. N, I, S, and SI indicate Non-adoption, Intensification, Sustainable, and SI, respectively.

Table 2A.2: CRE-MNLS estimates for net crop income (1,000 TZS)

Variables	Intensification		Sustainable		SI	
	Coef.	SE	Coef.	SE	Coef.	SE
Male-headed HH (yes = 1)	0.134	0.227	0.020	0.097	-0.092	0.195
Age of HH head (years)	-0.022	0.039	0.028	0.019	0.041	0.038
Education of HH head (years)	0.142***	0.030	0.013	0.013	0.145***	0.026
Family labor (number of adults per acre)	-0.159*	0.091	0.005	0.044	-0.021	0.095
Total cultivated land (acres)	-0.022	0.024	-0.001	0.011	-0.030	0.020
Off-farm income (yes = 1)	0.268	0.279	-0.018	0.140	-0.008	0.250
Farm assets (1,000 TZS)	0.000	0.000	0.000	0.000	0.000	0.000
Livestock ownership (yes = 1)	0.372**	0.185	0.592***	0.088	1.047***	0.166
Access to credit (yes = 1)	0.573**	0.284	0.008	0.154	0.871***	0.247
Membership (SACCOS) (yes = 1)	0.807**	0.347	0.038	0.211	0.671**	0.317
Extension from gov't/NGO (yes = 1)	0.662***	0.242	-0.092	0.149	0.804***	0.215
Distance to main road (km)	-0.009*	0.005	-0.003	0.002	-0.012***	0.004
Distance to town (km)	-0.009***	0.003	-0.002	0.001	-0.008***	0.002
Distance to main market (km)	0.007***	0.002	0.003***	0.001	0.008***	0.002
Cooperatives (yes = 1)	0.203	0.180	-0.045	0.084	-0.248	0.163
Input supplier (yes = 1)	0.077	0.179	-0.111	0.088	0.114	0.160
Drought/Flood (yes = 1)	-0.169	0.318	-0.043	0.120	-0.546*	0.301
Crop disease/Pests (yes = 1)	0.020	0.318	0.035	0.139	-0.027	0.275
Total rainfall (mm)	0.001	0.001	-0.001	0.000	0.000	0.001
Soil nutrient constraint (yes = 1)	-0.102	0.197	0.081	0.087	0.234	0.181
Inorganic fertilizer price (TZS/kg)	0.000*	0.000	0.000	0.000	0.000	0.000
Lagged price of maize (TZS/kg)	-0.003	0.003	0.001	0.001	0.000	0.003
Lagged price of rice (TZS/kg)	-0.001	0.001	-0.001	0.001	-0.001	0.001
Bean price (TZS/kg)	-0.001	0.001	0.000	0.001	0.001	0.001
Groundnut price (TZS/kg)	0.000	0.001	0.000	0.000	0.000	0.000
Year dummy (2010/11)	0.859*	0.511	-0.101	0.204	0.511	0.441
Year dummy (2012/13)	1.434***	0.428	0.240	0.182	0.715*	0.377
T2 dummy	0.098	0.261	-0.236**	0.104	0.372	0.237
T3 dummy	0.044	0.253	-0.211**	0.104	0.204	0.235
Constant	-6.620	1.799	-2.976	0.660	-4.613	1.508
Joint significance of excluded IVs: $\chi^2(4)$	276.49***		165.54***		359.18***	
Joint significance of time-varying covariates: $\chi^2(11)$	8.41		12.76		10.06	
Wald χ^2			1141.23***			
Number of observations			3,641			

Notes: SE is standard errors. Non-adoption is the reference category. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Table 2A.3: CRE-MNLS estimates for net crop income (1,000 TZS) per acre

Variables	Intensification		Sustainable		SI	
	Coef.	SE	Coef.	SE	Coef.	SE
Male-headed HH (yes = 1)	0.135	0.227	0.007	0.096	-0.092	0.196
Age of HH head (years)	-0.022	0.039	0.027	0.019	0.041	0.038
Education of HH head (years)	0.142***	0.030	0.014	0.013	0.145***	0.026
Family labor (number of adults per acre)	-0.157*	0.090	0.006	0.044	-0.021	0.095
Total cultivated land (acres)	-0.022	0.024	-0.002	0.011	-0.031	0.020
Off-farm income (yes = 1)	0.269	0.279	-0.016	0.140	-0.011	0.250
Farm assets (1,000 TZS)	0.000	0.000	0.000	0.000	0.000	0.000
Livestock ownership (yes = 1)	0.394**	0.182	0.645***	0.086	1.063***	0.163
Access to credit (yes = 1)	0.574**	0.284	0.010	0.154	0.871***	0.247
Membership (SACCOS) (yes = 1)	0.811**	0.348	0.025	0.210	0.675**	0.318
Extension from gov't/NGO (yes = 1)	0.656***	0.243	-0.071	0.149	0.800***	0.216
Distance to main road (km)	-0.009*	0.005	-0.004*	0.002	-0.012***	0.004
Distance to town (km)	-0.010***	0.003	-0.002	0.001	-0.008***	0.003
Distance to main market (km)	0.007***	0.002	0.003***	0.001	0.008***	0.002
Cooperatives (yes = 1)	0.199	0.180	-0.041	0.084	-0.245	0.163
Input supplier (yes = 1)	0.079	0.177	-0.100	0.088	0.108	0.159
Drought/Flood (yes = 1)	-0.170	0.317	-0.055	0.119	-0.545*	0.301
Crop disease/Pests (yes = 1)	0.009	0.319	0.033	0.139	-0.029	0.276
Total rainfall (mm)	0.001	0.001	0.000	0.000	0.000	0.001
Soil nutrient constraint (yes = 1)	-0.116	0.197	0.065	0.087	0.225	0.181
Inorganic fertilizer price (TZS/kg)	0.000	0.000	0.000	0.000	0.000	0.000
Lagged price of maize (TZS/kg)	-0.003	0.003	0.001	0.001	0.000	0.003
Lagged price of rice (TZS/kg)	-0.001	0.001	-0.001	0.001	-0.001	0.001
Bean price (TZS/kg)	-0.001	0.001	0.000	0.001	0.001	0.001
Groundnut price (TZS/kg)	0.000	0.001	0.000	0.000	0.000	0.000
Year dummy (2010/11)	0.887*	0.516	-0.167	0.204	0.558	0.445
Year dummy (2012/13)	1.480***	0.434	0.200	0.183	0.774**	0.382
T2 dummy	0.104	0.261	-0.220**	0.104	0.379	0.237
T3 dummy	0.053	0.253	-0.192*	0.103	0.214	0.235
Electoral threat	-0.685	0.501	-0.225**	0.105	-0.267	0.371
Proportion receiving agricultural advice	0.002	0.005	-0.002	0.003	0.002	0.004
Proportion adopting inorganic fertilizer	0.046***	0.003	0.006***	0.002	0.046***	0.003
Proportion adopting maize-legume IC	0.003	0.003	0.014***	0.001	0.011***	0.003
Constant	-6.654***	1.797	-3.053***	0.661	-4.569***	1.502
Joint significance of excluded IVs: $\chi^2(4)$	279.42***		156.60***		362.36***	
Joint significance of time-varying covariates: $\chi^2(11)$	8.64		12.57		10.18	
Wald χ^2			1130.97***			
Number of observations			3,641			

Notes: SE is standard errors. Non-adoption is the reference category. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Table 2A.4: CRE-MNLS estimates for net crop income (1,000 TZS) per adult equivalent

Variables	Intensification		Sustainable		SI	
	Coef.	SE	Coef.	SE	Coef.	SE
Male-headed HH (yes = 1)	0.161	0.228	0.017	0.097	-0.044	0.197
Age of HH head (years)	-0.021	0.039	0.028	0.019	0.043	0.038
Education of HH head (years)	0.142***	0.030	0.013	0.013	0.146***	0.026
Family labor (number of adults per acre)	-0.153	0.093	0.004	0.044	-0.006	0.096
Total cultivated land (acres)	-0.021	0.024	-0.002	0.011	-0.029	0.020
Off-farm income (yes = 1)	0.266	0.280	-0.022	0.140	0.003	0.252
Farm assets (1,000 TZS)	0.000	0.000	0.000	0.000	0.000	0.000
Livestock ownership (yes = 1)	0.355*	0.185	0.598***	0.088	1.034***	0.167
Access to credit (yes = 1)	0.602**	0.284	0.005	0.154	0.903***	0.247
Membership (SACCOS) (yes = 1)	0.782**	0.348	0.040	0.211	0.653**	0.319
Extension from gov't/NGO (yes = 1)	0.642***	0.242	-0.089	0.149	0.783***	0.216
Distance to main road (km)	-0.008	0.005	-0.003	0.002	-0.010**	0.005
Distance to town (km)	-0.009***	0.003	-0.002	0.001	-0.008***	0.002
Distance to main market (km)	0.007***	0.002	0.003***	0.001	0.008***	0.002
Cooperatives (yes = 1)	0.256	0.180	-0.053	0.085	-0.198	0.164
Input supplier (yes = 1)	0.006	0.180	-0.103	0.089	0.011	0.163
Drought/Flood (yes = 1)	-0.135	0.318	-0.045	0.120	-0.497	0.302
Crop disease/Pests (yes = 1)	0.028	0.318	0.033	0.139	-0.015	0.276
Total rainfall (mm)	0.001	0.001	0.000	0.000	0.000	0.001
Soil nutrient constraint (yes = 1)	0.041	0.204	0.066	0.090	0.429**	0.188
Inorganic fertilizer price (TZS/kg)	0.000*	0.000	0.000	0.000	-0.000	0.000
Lagged price of maize (TZS/kg)	-0.001	0.003	0.001	0.001	0.003	0.003
Lagged price of rice (TZS/kg)	-0.002	0.001	-0.001	0.001	-0.003**	0.001
Bean price (TZS/kg)	-0.001	0.001	-0.000	0.001	0.001	0.001
Groundnut price (TZS/kg)	-0.000	0.001	-0.000	0.000	-0.000	0.000
Year dummy (2010/11)	0.501	0.538	-0.061	0.210	0.016	0.466
Year dummy (2012/13)	1.617***	0.440	0.244	0.182	0.980**	0.389
T2 dummy	0.103	0.261	-0.233**	0.104	0.393*	0.238
T3 dummy	0.030	0.254	-0.202*	0.104	0.181	0.237
Electoral threat	-0.639	0.492	-0.225	0.107	-0.210	0.356
Number of subsidized fertilizer vouchers	0.000**	0.000	0.000	0.000	0.000***	0.000
Proportion adopting inorganic fertilizer	0.045***	0.003	0.004**	0.002	0.045***	0.003
Proportion adopting organic fertilizer	0.001	0.004	0.006***	0.002	0.000	0.003
Proportion adopting maize-legume IC	0.002	0.003	0.014***	0.001	0.010***	0.003
Constant	-7.930***	1.906	-2.820***	0.684	-5.880***	1.593
Joint significance of excluded IVs: $\chi^2(5)$	277.64***		165.96***		365.46***	
Joint significance of time-varying covariates: $\chi^2(11)$	10.61		12.27		10.89	
Wald χ^2			1141.35***			
Number of observations			3,641			

Notes: SE is standard errors. Non-adoption is the reference category. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Table 2A.5: CRE-MNLS estimates for crop productivity

Variables	Intensification		Sustainable		SI	
	Coef.	SE	Coef.	SE	Coef.	SE
Male-headed HH (yes = 1)	0.188	0.211	0.019	0.097	-0.006	0.179
Age of HH head (years)	-0.014	0.035	0.029	0.019	0.041	0.034
Education of HH head (years)	0.148***	0.028	0.013	0.013	0.151***	0.024
Family labor (number of adults per acre)	-0.123	0.081	0.005	0.045	0.000	0.083
Total cultivated land (acres)	-0.021	0.024	-0.001	0.010	-0.029	0.020
Off-farm income (yes = 1)	0.232	0.257	-0.018	0.140	-0.077	0.225
Farm assets (1,000 TZS)	0.000	0.000	0.000	0.000	0.000	0.000
Livestock ownership (yes = 1)	0.272	0.170	0.575***	0.087	0.991***	0.151
Access to credit (yes = 1)	0.576**	0.261	0.016	0.154	0.847***	0.226
Membership (SACCOS) (yes = 1)	1.040***	0.317	0.065	0.210	0.788***	0.292
Extension from gov't/NGO (yes = 1)	0.654***	0.223	-0.070	0.148	0.820***	0.195
Distance to main road (km)	-0.009*	0.005	-0.003*	0.002	-0.016***	0.004
Distance to town (km)	-0.014***	0.003	-0.002	0.001	-0.011***	0.002
Distance to main market (km)	0.010***	0.002	0.003***	0.001	0.011***	0.002
Cooperatives (yes = 1)	0.439***	0.164	-0.017	0.084	-0.004	0.146
Input supplier (yes = 1)	0.401**	0.162	-0.095	0.087	0.469***	0.143
Drought/Flood (yes = 1)	-0.156	0.292	-0.057	0.119	-0.553**	0.276
Crop disease/Pests (yes = 1)	0.015	0.297	0.035	0.139	0.002	0.253
Total rainfall (mm)	0.001	0.001	-0.001	0.000	-0.000	0.001
Soil nutrient constraint (yes = 1)	-0.215	0.180	0.084	0.087	0.089	0.163
Inorganic fertilizer price (TZS/kg)	0.000**	0.000	0.000	0.000	-0.000	0.000
Lagged price of maize (TZS/kg)	-0.004	0.003	0.001	0.001	-0.001	0.002
Lagged price of rice (TZS/kg)	0.000	0.001	-0.001	0.001	-0.000	0.001
Bean price (TZS/kg)	-0.001	0.001	-0.000	0.001	0.000	0.001
Groundnut price (TZS/kg)	-0.001	0.000	0.000	0.000	-0.000	0.000
Year dummy (2010/11)	1.331***	0.480	-0.103	0.205	1.029***	0.409
Year dummy (2012/13)	1.784***	0.394	0.237	0.184	1.112***	0.345
T2 dummy	0.087	0.242	-0.236**	0.104	0.247	0.214
T3 dummy	0.177	0.231	-0.210**	0.104	0.247	0.210
Electoral threat	-0.572	0.420	-0.231**	0.107	-0.192	0.279
Proportion receiving agricultural advice	0.027***	0.004	-0.001	0.003	0.026***	0.003
Proportion adopting organic fertilizer	0.012***	0.003	0.007***	0.002	0.011***	0.003
Proportion adopting maize-legume IC	0.009***	0.003	0.014***	0.001	0.017***	0.002
Constant	-5.622***	1.523	-2.997***	0.668	-4.630***	1.285
Joint significance of excluded IVs: $\chi^2(4)$	92.67***		166.16***		156.38***	
Joint significance of time-varying covariates: $\chi^2(11)$	18.25*		12.74		15.05	
Wald χ^2			942.33***			
Number of observations			3,641			

Notes: SE is standard errors. Non-adoption is the reference category. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Table 2A.6: CRE-MNLS estimates for modified HDDS

Variables	Intensification		Sustainable		SI	
	Coef.	SE	Coef.	SE	Coef.	SE
Male-headed HH (yes = 1)	0.127	0.226	0.008	0.096	-0.100	0.195
Age of HH head (years)	-0.023	0.039	0.027	0.019	0.040	0.038
Education of HH head (years)	0.143***	0.030	0.014	0.013	0.145***	0.026
Family labor (number of adults per acre)	-0.160*	0.091	0.006	0.044	-0.022	0.096
Total cultivated land (acres)	-0.022	0.024	-0.002	0.011	-0.030	0.020
Off-farm income (yes = 1)	0.268	0.279	-0.015	0.140	-0.009	0.250
Farm assets (1,000 TZS)	0.000	0.000	0.000	0.000	0.000	0.000
Livestock ownership (yes = 1)	0.389**	0.181	0.643***	0.086	1.058***	0.163
Access to credit (yes = 1)	0.571**	0.284	0.009	0.154	0.868***	0.247
Membership (SACCOS) (yes = 1)	0.801**	0.347	0.028	0.210	0.665**	0.317
Extension from gov't/NGO (yes = 1)	0.669***	0.242	-0.077	0.149	0.812***	0.215
Distance to main road (km)	-0.009*	0.005	-0.004*	0.002	-0.012***	0.004
Distance to town (km)	-0.009***	0.003	-0.002	0.001	-0.008***	0.002
Distance to main market (km)	0.007***	0.002	0.003***	0.001	0.008***	0.002
Cooperatives (yes = 1)	0.207	0.179	-0.046	0.084	-0.242	0.163
Input supplier (yes = 1)	0.077	0.177	-0.100	0.088	0.107	0.159
Drought/Flood (yes = 1)	-0.172	0.317	-0.054	0.119	-0.545*	0.301
Crop disease/Pests (yes = 1)	0.021	0.317	0.032	0.139	-0.023	0.275
Total rainfall (mm)	0.001	0.001	-0.000	0.000	-0.000	0.001
Soil nutrient constraint (yes = 1)	-0.109	0.196	0.065	0.087	0.230	0.181
Inorganic fertilizer price (TZS/kg)	0.000	0.000	0.000	0.000	-0.000	0.000
Lagged price of maize (TZS/kg)	-0.003	0.003	0.001	0.001	0.000	0.003
Lagged price of rice (TZS/kg)	-0.001	0.001	-0.001	0.001	-0.001	0.001
Bean price (TZS/kg)	-0.001	0.001	-0.000	0.001	0.001	0.001
Groundnut price (TZS/kg)	-0.000	0.001	0.000	0.000	-0.000	0.000
Year dummy (2010/11)	0.843*	0.509	-0.155	0.203	0.514	0.439
Year dummy (2012/13)	1.434***	0.425	0.215	0.182	0.732*	0.375
T2 dummy	0.104	0.261	-0.220**	0.104	0.378	0.237
T3 dummy	0.049	0.252	-0.192*	0.103	0.210	0.235
Electoral threat	-0.710	0.501	-0.223	0.105	-0.284	0.373
Proportion adopting inorganic fertilizer	0.047	0.003	0.006	0.002	0.047	0.003
Proportion adopting maize-legume IC	0.003	0.003	0.014	0.001	0.011	0.003
Constant	-6.652***	1.795	-3.077***	0.660	-4.569***	1.501
Joint significance of excluded IVs: $\chi^2(3)$	279.00***		156.42***		362.64***	
Joint significance of time-varying covariates: $\chi^2(11)$	8.55		12.67		10.08	
Wald χ^2			1,131.36***			
Number of observations			3,641			

Notes: SE is standard errors. Non-adoption is the reference category. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Table 2A.7: CRE-MNLS estimates for food expenditure per adult equivalent

Variables	Intensification		Sustainable		SI	
	Coef.	SE	Coef.	SE	Coef.	SE
Male-headed HH (yes = 1)	0.113	0.226	0.005	0.096	-0.107	0.195
Age of HH head (years)	-0.023	0.039	0.028	0.019	0.041	0.038
Education of HH head (years)	0.142***	0.030	0.015	0.013	0.146***	0.026
Family labor (number of adults per acre)	-0.161*	0.091	0.004	0.044	-0.023	0.095
Total cultivated land (acres)	-0.022	0.025	-0.001	0.011	-0.030	0.020
Off-farm income (yes = 1)	0.252	0.279	-0.025	0.140	-0.015	0.250
Farm assets (1,000 TZS)	0.000	0.000	0.000	0.000	0.000	0.000
Livestock ownership (yes = 1)	0.375**	0.185	0.597***	0.088	1.051***	0.166
Access to credit (yes = 1)	0.587**	0.284	0.015	0.154	0.880***	0.247
Membership (SACCOS) (yes = 1)	0.781**	0.347	0.028	0.210	0.662**	0.317
Extension from gov't/NGO (yes = 1)	0.677***	0.241	-0.086	0.149	0.809***	0.215
Distance to main road (km)	-0.009*	0.005	-0.004*	0.002	-0.013***	0.004
Distance to town (km)	-0.009***	0.003	-0.001	0.001	-0.008***	0.002
Distance to main market (km)	0.007***	0.002	0.003***	0.001	0.008***	0.002
Cooperatives (yes = 1)	0.194	0.180	-0.054	0.084	-0.257	0.163
Input supplier (yes = 1)	0.074	0.178	-0.127	0.088	0.107	0.160
Drought/Flood (yes = 1)	-0.159	0.318	-0.033	0.120	-0.537*	0.301
Crop disease/Pests (yes = 1)	0.033	0.317	0.045	0.139	-0.023	0.275
Total rainfall (mm)	0.001	0.001	-0.001	0.000	0.000	0.001
Soil nutrient constraint (yes = 1)	-0.080	0.196	0.095	0.087	0.243	0.180
Inorganic fertilizer price (TZS/kg)	0.000*	0.000	0.000	0.000	0.000	0.000
Lagged price of maize (TZS/kg)	-0.004	0.003	0.001	0.001	0.000	0.003
Lagged price of rice (TZS/kg)	0.000	0.001	-0.001	0.001	-0.001	0.001
Bean price (TZS/kg)	-0.001	0.001	0.000	0.001	0.001	0.001
Groundnut price (TZS/kg)	0.000	0.001	0.000	0.000	0.000	0.000
Year dummy (2010/11)	0.904*	0.504	-0.029	0.201	0.567	0.440
Year dummy (2012/13)	1.387***	0.419	0.264	0.181	0.717*	0.375
T2 dummy	0.099	0.261	-0.238**	0.104	0.371	0.237
T3 dummy	0.055	0.252	-0.207**	0.104	0.209	0.235
Proportion adopting inorganic fertilizer	0.046***	0.003	0.004**	0.002	0.046***	0.003
Proportion adopting organic fertilizer	0.002	0.003	0.006***	0.002	0.002	0.003
Proportion adopting maize-legume IC	0.003	0.003	0.014***	0.001	0.011***	0.003
Constant	-7.013***	1.771	-2.964***	0.660	-4.667***	1.497
Joint significance of excluded IVs: $\chi^2(3)$	277.16***		165.08***		360.75***	
Joint significance of time-varying covariates: $\chi^2(11)$	8.58		13.55		10.04	
Wald χ^2			1143.15***			
Number of observations			3,641			

Notes: SE is standard errors. Non-adoption is the reference category. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Table 2A.8: CRE-MNLS estimates for FCS

Variables	Intensification		Sustainable		SI	
	Coef.	SE	Coef.	SE	Coef.	SE
Male-headed HH (yes = 1)	-0.317	0.312	-0.009	0.156	-0.082	0.296
Age of HH head (years)	-0.020	0.061	0.067**	0.031	0.081	0.054
Education of HH head (years)	0.113***	0.044	0.028	0.021	0.152***	0.039
Family labor (number of adults per acre)	-0.078	0.209	-0.040	0.052	0.068	0.114
Total cultivated land (acres)	-0.014	0.037	0.004	0.018	-0.008	0.025
Off-farm income (yes = 1)	0.385	0.421	0.100	0.205	0.223	0.379
Farm assets (1,000 TZS)	0.000	0.000	0.000	0.000	0.000	0.000
Livestock ownership (yes = 1)	0.446*	0.257	0.663***	0.136	1.040***	0.238
Access to credit (yes = 1)	0.472	0.419	-0.115	0.254	0.933**	0.376
Membership (SACCOS) (yes = 1)	0.817*	0.476	-0.164	0.299	0.464	0.460
Extension from gov't/NGO (yes = 1)	0.797**	0.357	-0.251	0.266	0.668**	0.330
Distance to main road (km)	-0.009	0.007	-0.007**	0.003	-0.008	0.006
Distance to town (km)	-0.007*	0.004	0.000	0.002	-0.005	0.004
Distance to main market (km)	0.009***	0.003	0.003**	0.002	0.008***	0.002
Cooperatives (yes = 1)	0.218	0.261	-0.207	0.134	-0.336	0.243
Input supplier (yes = 1)	0.008	0.258	-0.097	0.140	-0.137	0.240
Drought/Flood (yes = 1)	0.393	0.414	0.139	0.191	-0.351	0.458
Crop disease/Pests (yes = 1)	-0.527	0.491	-0.319	0.229	-0.477	0.423
Total rainfall (mm)	0.001	0.001	-0.001**	0.001	-0.002	0.001
Soil nutrient constraint (yes = 1)	0.203	0.301	0.149	0.147	0.498*	0.283
Inorganic fertilizer price (TZS/kg)	-0.000	0.000	0.000	0.000	-0.000	0.000
Lagged price of maize (TZS/kg)	0.001	0.005	0.007***	0.003	0.012**	0.005
Lagged price of rice (TZS/kg)	-0.005**	0.002	-0.003***	0.001	-0.007***	0.002
Bean price (TZS/kg)	-0.000	0.003	0.002	0.002	0.004	0.003
Groundnut price (TZS/kg)	-0.002*	0.001	-0.000	0.001	-0.001	0.001
Year dummy (2012/13)	0.768	0.634	0.408	0.299	1.331**	0.587
Number of subsidized fertilizer vouchers	0.000	0.000	0.000	0.000	0.000	0.000
Proportion adopting inorganic fertilizer	0.046	0.004	0.005	0.003	0.046	0.004
Proportion adopting maize-legume IC	0.005	0.005	0.014	0.002	0.011	0.004
Constant	-11.951***	3.950	-6.630***	1.409	-11.805***	3.682
Joint significance of excluded IVs: $\chi^2(3)$	145.21***		61.36***		181.58***	
Joint significance of time-varying covariates: $\chi^2(11)$	13.17		19.25*		14.39	
Wald χ^2			559.24***			
Number of observations			1,622			

Notes: SE is standard errors. Non-adoption is the reference category. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Table 2A.9: CRE-MESR second stage estimation results for net crop income (1,000 TZS)

Variables	Adoption choice (*j*)							
	Non-adoption		Intensification		Sustainable		SI	
	Coef.	SE	Coef.	SE	Coef.	SE	Coef.	SE
Male-headed HH (yes = 1)	110.22***	20.08	101.37	141.72	103.36***	23.22	-6.93	130.39
Age of HH head (years)	3.34	5.74	5.56	27.53	4.77	5.80	-1.31	31.31
Education of HH head (years)	4.44	3.52	4.89	24.54	2.17	3.54	14.48	27.62
Family labor (number of adults per acre)	8.95	14.34	14.85	73.57	-16.81	16.02	-42.64	59.22
Total cultivated land (acres)	6.76	4.39	18.88	28.23	14.61*	8.77	12.94	22.36
Off-farm income (yes = 1)	36.48	39.88	130.85	159.64	46.57	37.74	-4.97	197.86
Farm assets (1,000 TZS)	0.01	0.01	-0.07	0.07	0.01	0.01	0.02	0.07
Livestock ownership (yes = 1)	147.51***	30.46	95.33	166.31	149.43***	30.11	-96.24	121.91
Access to credit (yes = 1)	-21.99	38.27	-166.97	208.99	-20.16	45.22	342.82*	181.98
Membership (SACCOS) (yes = 1)	54.91	53.84	-195.33	240.43	-59.53	53.75	-319.55**	158.02
Extension from gov't/NGO (yes = 1)	-50.75	36.47	123.99	179.33	51.54	52.97	158.09	151.60
Distance to main road (km)	0.55	0.63	0.18	4.10	-1.81***	0.70	-6.84**	3.19
Distance to town (km)	1.54***	0.35	3.23	2.36	2.23***	0.47	7.03***	2.15
Distance to main market (km)	-0.49*	0.28	-0.39	1.19	0.11	0.32	-0.47	1.12
Cooperatives (yes = 1)	-22.25	25.42	55.75	133.03	-55.23**	25.90	-137.55	106.54
Input supplier (yes = 1)	32.49	22.61	-161.85	121.23	5.95	28.62	97.83	96.88
Drought/Flood (yes = 1)	-66.53**	29.87	439.58	353.31	17.25	37.37	46.49	261.62
Crop disease/Pests (yes = 1)	-40.47	31.76	-101.01	182.28	-71.65*	36.87	167.17	220.25
Total rainfall (mm)	0.01	0.10	0.52	0.90	0.02	0.14	-0.07	0.59
Soil nutrient constraint (yes = 1)	7.26	19.32	250.13	159.57	-24.65	25.52	-23.12	109.18
Inorganic fertilizer price (TZS/kg)	0.00	0.02	0.07	0.13	0.01	0.02	-0.07	0.10
Lagged price of maize (TZS/kg)	0.56*	0.34	1.41	3.06	-0.14	0.42	0.81	1.93
Lagged price of rice (TZS/kg)	-0.26*	0.15	-0.81	0.92	-0.03	0.18	0.40	0.76
Bean price (TZS/kg)	0.32**	0.14	1.95	1.43	0.14	0.18	0.41	0.75
Groundnut price (TZS/kg)	0.03	0.07	-0.43	0.42	0.06	0.08	0.23	0.34

Table 2A.9 (cont'd)

Variables	Adoption choice (*j*)							
	Non-adoption		Intensification		Sustainable		SI	
	Coef.	SE	Coef.	SE	Coef.	SE	Coef.	SE
Year dummy (2010/11)	-23.13	54.09	250.18	606.91	23.34	58.29	-390.81	347.30
Year dummy (2012/13)	55.65	45.32	270.52	451.63	57.81	63.35	-347.00	297.53
T2 dummy	-5.24	26.20	204.19	227.12	-46.29	30.60	-14.35	190.38
T3 dummy	51.60**	25.12	210.56	231.35	35.10	31.60	-22.87	200.53
Constant	643.18***	171.69	288.33	2012.07	34.78	212.59	2100.94	1347.78
Joint significance of excluded IVs	F(4,1572)=0.85		F(4,195)=1.51		F(4,1395)=0.90		F(4,299)=1.16	
Joint significance of time-varying covariates	22.99**		4.18		12.39		13.95	
Ancillary								
σ^2	261,497***	60,155	615,060	883,982	199,524***	44,462	1,629,908	1,118,932
λ_1			-0.15	0.53	-0.24	0.16	0.81*	0.47
λ_2	-1.10**	0.49			-0.18	0.52	-0.89**	0.39
λ_3	0.45*	0.24	0.61	0.53			-0.08	0.42
λ_4	0.78	0.55	-0.46	0.42	0.38	0.48		
Number of observations	1,617		240		1,440		344	

Notes: Non-adoption is the reference category. Standard errors were bootstrapped with 100 replications. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Table 2A.10: CRE-MESR second stage estimation results for net crop income (1,000 TZS) per acre

	Adoption choice (*j*)							
Variables	Non-adoption		Intensification		Sustainable		SI	
	Coef.	SE	Coef.	SE	Coef.	SE	Coef.	SE
Male-headed HH (yes = 1)	15.60**	6.30	5.93	35.40	10.18	6.34	-4.44	20.51
Age of HH head (years)	-0.20	0.85	1.71	8.31	2.29	1.73	7.16	5.58
Education of HH head (years)	0.31	0.95	1.64	5.64	0.13	0.89	1.03	4.24
Family labor (number of adults per acre)	11.51***	3.96	18.38	16.61	17.97**	7.97	-6.01	14.46
Total cultivated land (acres)	-1.85**	0.81	-2.64	4.72	-1.45	1.22	-2.41	2.11
Off-farm income (yes = 1)	4.34	8.95	45.48	40.42	-6.47	9.61	10.02	30.19
Farm assets (1,000 TZS)	0.00	0.00	-0.01	0.01	0.00	0.00	0.00	0.01
Livestock ownership (yes = 1)	14.97*	8.81	-24.31	38.63	16.74**	8.04	2.74	19.71
Access to credit (yes = 1)	-8.79	10.00	-17.59	41.95	-14.04	10.86	108.04***	32.31
Membership (SACCOS) (yes = 1)	6.39	15.57	-27.71	59.95	2.52	13.66	-63.06**	31.83
Extension from gov't/NGO (yes = 1)	-10.33	10.43	37.70	42.47	14.66	15.44	26.20	23.76
Distance to main road (km)	0.09	0.16	1.45	0.92	-0.04	0.17	-0.15	0.52
Distance to town (km)	0.05	0.11	0.36	0.44	0.31***	0.09	0.60**	0.30
Distance to main market (km)	0.11	0.08	0.01	0.27	-0.08	0.06	-0.08	0.19
Cooperatives (yes = 1)	5.40	5.78	25.80	27.33	0.07	5.75	-12.01	16.49
Input supplier (yes = 1)	3.67	6.04	-39.49	24.95	2.84	5.94	11.94	17.00
Drought/Flood (yes = 1)	-6.38	7.27	49.02	57.77	3.63	8.14	12.07	39.55
Crop disease/Pests (yes = 1)	-11.43	8.11	-0.60	38.90	-2.91	8.44	27.48	38.54
Total rainfall (mm)	0.05*	0.03	0.03	0.17	0.00	0.03	0.03	0.11
Soil nutrient constraint (yes = 1)	-10.00*	5.61	0.97	31.93	-16.42***	6.08	-2.51	24.25
Inorganic fertilizer price (TZS/kg)	0.01	0.01	0.04	0.03	0.01	0.01	-0.02	0.01
Lagged price of maize (TZS/kg)	0.07	0.08	-0.23	0.61	0.02	0.10	0.23	0.37
Lagged price of rice (TZS/kg)	-0.05	0.04	-0.05	0.18	0.00	0.03	-0.09	0.12
Bean price (TZS/kg)	0.06*	0.03	0.05	0.29	0.00	0.04	0.09	0.13
Groundnut price (TZS/kg)	0.04	0.02	-0.05	0.09	0.05***	0.02	0.04	0.06

Table 2A.10. (cont'd)

Variables	Adoption choice (j)							
	Non-adoption		Intensification		Sustainable		SI	
	Coef.	SE	Coef.	SE	Coef.	SE	Coef.	SE
Year dummy (2010/11)	-32.96**	16.19	78.10	103.40	-40.46***	14.15	-66.85	68.48
Year dummy (2012/13)	10.44	13.27	73.26	87.44	-16.91	13.14	-58.64	53.46
T2 dummy	0.00	8.01	-28.01	50.97	-8.33	6.63	21.93	28.70
T3 dummy	4.24	6.58	-47.41	49.28	10.51	8.23	5.73	27.71
Constant	22.56	46.19	115.58	393.51	12.21	60.12	404.05	218.07
Joint significance of excluded IVs	F(4,1572)=0.51		F(4,195)=1.03		F(4,1395)=0.76		F(4,299)=0.82	
Joint significance of time-varying covariates	7.01		4.52		24.00**		17.71*	
Ancillary								
σ^2	21,111***	6,546	35,214	54,002	10,728***	1,839	46,240*	25,026
λ_1			0.08	0.52	-0.27	0.19	0.11	0.50
λ_2	0.65	0.42			0.12	0.44	-0.96***	0.34
λ_3	0.69***	0.16	0.53	0.58			0.72**	0.36
λ_4	-1.05***	0.39	-0.79*	0.43	0.11	0.39		
Number of observations	1,617		240		1,440		344	

Notes: Non-adoption is the reference category. Standard errors were bootstrapped with 100 replications. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Table 2A.11: CRE-MESR second stage estimation results for net crop income (1,000 TZS) per adult equivalent

Variables	Adoption choice (*j*)							
	Non-adoption		Intensification		Sustainable		SI	
	Coef.	SE	Coef.	SE	Coef.	SE	Coef.	SE
Male-headed HH (yes = 1)	17.15***	4.90	26.47	30.38	14.76**	6.53	-15.28	29.95
Age of HH head (years)	0.37	1.32	1.55	5.81	2.49	1.90	4.27	7.38
Education of HH head (years)	1.31	0.84	-3.27	4.76	-0.28	0.86	5.22	5.47
Family labor (number of adults per acre)	2.95	4.35	0.89	14.89	-8.03*	4.85	-6.62	14.28
Total cultivated land (acres)	0.84	0.68	8.72	6.19	3.63***	1.01	3.12	4.83
Off-farm income (yes = 1)	8.06	9.46	22.93	35.29	-1.48	8.96	-19.47	42.02
Farm assets (1,000 TZS)	0.00	0.00	-0.01	0.01	0.00	0.00	0.01	0.01
Livestock ownership (yes = 1)	13.54**	6.82	-3.35	36.50	9.85	6.50	-23.95	26.00
Access to credit (yes = 1)	3.79	12.15	-26.46	43.07	-10.90	8.08	87.99	36.39
Membership (SACCOS) (yes = 1)	-6.08	9.82	-54.04	50.62	-12.81	12.84	-67.43*	36.58
Extension from gov't/NGO (yes = 1)	-18.12***	6.91	18.26	39.94	15.30	14.00	24.93	31.76
Distance to main road (km)	0.13	0.16	1.13	1.00	-0.38**	0.17	-1.34**	0.67
Distance to town (km)	0.33***	0.08	0.52	0.45	0.39***	0.11	1.61***	0.44
Distance to main market (km)	-0.13*	0.07	-0.26	0.29	-0.03	0.07	-0.32	0.23
Cooperatives (yes = 1)	1.85	5.65	29.85	25.54	-7.68	5.90	-35.40	23.36
Input supplier (yes = 1)	6.21	4.73	-38.32	26.35	3.68	7.55	9.61	19.55
Drought/Flood (yes = 1)	-10.05	7.05	34.71	64.63	9.24	10.61	-27.96	48.03
Crop disease/Pests (yes = 1)	-10.44	7.46	-1.26	42.87	-14.38	9.40	61.96	47.38
Total rainfall (mm)	0.01	0.03	0.06	0.19	0.02	0.04	-0.06	0.14
Soil nutrient constraint (yes = 1)	1.43	4.68	78.15**	35.04	-8.88	6.14	6.19	24.52
Inorganic fertilizer price (TZS/kg)	0.00	0.00	0.02	0.03	0.00	0.00	-0.01	0.02
Lagged price of maize (TZS/kg)	0.13	0.08	0.43	0.61	-0.02	0.10	0.41	0.39
Lagged price of rice (TZS/kg)	-0.06*	0.03	-0.17	0.20	-0.03	0.04	0.09	0.16
Bean price (TZS/kg)	0.07**	0.03	0.35	0.31	0.02	0.05	0.27*	0.16
Groundnut price (TZS/kg)	0.01	0.01	-0.06	0.09	0.01	0.02	0.02	0.07

Table 2A.11. (cont'd)

Variables	Adoption choice (*j*)							
	Non-adoption		Intensification		Sustainable		SI	
	Coef.	SE	Coef.	SE	Coef.	SE	Coef.	SE
Year dummy (2010/11)	-11.83	12.22	5.73	111.75	4.24	15.43	-118.69*	71.57
Year dummy (2012/13)	8.53	11.69	10.23	84.11	5.12	13.83	-125.79*	66.28
T2 dummy	-7.02	6.12	16.37	47.28	-10.74	7.35	-25.49	45.29
T3 dummy	6.52	5.92	14.82	46.06	6.76	7.12	-42.56	46.54
Constant	145.24***	39.99	100.07	457.97	16.45	56.53	647.60**	281.28
Joint significance of excluded IVs	F(5,1571)=0.43		F(5,194)=1.72		F(5,1394)=1.35		F(5,298)=0.82	
Joint significance of time-varying covariates	26.61***		4.75		10.80		18.49*	
Ancillary								
σ^2	10,845***	2,503	34,651	45,517	12,219***	3,468	84,063	55,547
λ_1			-0.11	0.54	-0.31**	0.15	0.89**	0.42
λ_2	-0.70	0.43			0.55	0.44	-0.87***	0.31
λ_3	0.57***	0.18	0.71	0.55			-0.19	0.43
λ_4	0.28	0.45	-0.59	0.38	-0.30	0.42		
Number of observations	1,617		240		1,440		344	

Notes: Non-adoption is the reference category. Standard errors were bootstrapped with 100 replications. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Table 2A.12: CRE-MESR second stage estimation results for crop productivity

Variables	Adoption choice (*j*)							
	Non-adoption		Intensification		Sustainable		SI	
	Coef.	SE	Coef.	SE	Coef.	SE	Coef.	SE
Male-headed HH (yes = 1)	43.83*	22.48	34.81	116.59	30.66	21.75	4.79	94.31
Age of HH head (years)	0.60	4.27	1.33	30.62	11.63*	6.32	33.64	27.77
Education of HH head (years)	0.63	3.30	14.22	21.87	-1.71	3.45	-3.15	19.67
Family labor (number of adults per acre)	42.66***	14.66	81.40	71.60	63.30**	26.20	96.09*	56.85
Total cultivated land (acres)	-6.11**	3.02	-12.47	16.06	-5.26	4.12	-2.47	10.60
Off-farm income (yes = 1)	16.95	35.55	264.71*	141.13	-21.40	34.08	19.92	138.00
Farm assets (1,000 TZS)	0.00	0.01	-0.01	0.03	0.00	0.00	0.00	0.05
Livestock ownership (yes = 1)	65.58**	31.06	-160.92	166.27	76.20***	26.36	-58.53	84.11
Access to credit (yes = 1)	-19.10	36.61	-4.96	201.24	-20.91	41.27	305.88**	139.49
Membership (SACCOS) (yes = 1)	8.34	51.54	-127.43	215.71	23.74	43.27	-156.62	118.28
Extension from gov't/NGO (yes = 1)	-50.04	34.87	217.68	178.91	54.13	47.44	105.82	104.39
Distance to main road (km)	0.26	0.60	3.52	3.57	-0.12	0.53	-1.84	2.25
Distance to town (km)	0.44	0.37	1.83	1.86	1.09***	0.31	3.66***	1.41
Distance to main market (km)	0.02	0.31	-0.50	1.06	-0.41*	0.23	-1.02	0.90
Cooperatives (yes = 1)	8.01	24.15	56.60	110.36	-15.05	18.45	-4.44	72.08
Input supplier (yes = 1)	-3.54	20.73	-209.28**	106.73	-2.70	21.49	-36.94	79.85
Drought/Flood (yes = 1)	-10.47	26.24	162.40	237.49	24.77	33.35	18.89	154.19
Crop disease/Pests (yes = 1)	-35.24	33.20	-106.79	153.11	-7.47	32.97	11.44	156.02
Total rainfall (mm)	0.17	0.12	0.07	0.64	-0.05	0.11	-0.49	0.48
Soil nutrient constraint (yes = 1)	-44.70*	23.47	-119.07	122.36	-56.22***	20.04	-50.12	96.96
Inorganic fertilizer price (TZS/kg)	0.02	0.02	0.10	0.12	0.02	0.02	0.00	0.10
Lagged price of maize (TZS/kg)	0.21	0.28	-0.39	2.16	0.00	0.29	1.92	1.35
Lagged price of rice (TZS/kg)	-0.26**	0.12	-0.21	0.62	-0.10	0.12	-0.70	0.47
Bean price (TZS/kg)	0.09	0.14	0.98	0.88	-0.13	0.14	0.08	0.54
Groundnut price (TZS/kg)	0.16*	0.09	-0.35	0.32	0.13**	0.06	0.19	0.20

Table 2A.12. (cont'd)

Variables	Adoption choice (*j*)							
	Non-adoption		Intensification		Sustainable		SI	
	Coef.	SE	Coef.	SE	Coef.	SE	Coef.	SE
Year dummy (2010/11)	-91.08	59.19	264.95	419.85	-60.14	56.17	-310.31	248.23
Year dummy (2012/13)	20.30	47.86	281.07	340.13	-70.98	50.45	-226.17	204.10
T2 dummy	1.39	29.46	-80.32	191.43	-26.71	22.56	-38.48	134.78
T3 dummy	15.48	22.85	-135.67	187.95	39.30*	23.37	-56.23	135.99
Constant	557.16***	167.20	1058.47	1,698.19	587.53***	163.27	1,741.38**	886.95
Joint significance of excluded IVs	F(4,1572)=0.36		F(4,195)=1.18		F(4,1395)=0.46		F(4,299)=1.30	
Joint significance of time-varying covariates	5.87		2.86		31.08***		17.85*	
Ancillary								
σ^2	309,416**	124,066	578,334	901,736	141,052***	44,279	515,045	508,778
λ_1			0.29	0.44	0.01	0.21	-0.64	0.54
λ_2	0.23	0.47			-0.66	0.49	0.23	0.57
λ_3	0.90***	0.17	0.48	0.63			0.73*	0.39
λ_4	-0.90**	0.39	-0.90	0.55	0.47	0.44		
Number of observations	1,617		240		1,440		344	

Notes: Non-adoption is the reference category. Standard errors were bootstrapped with 100 replications. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Table 2A.13: CRE-MESR second stage estimation results for modified HDDS

Variables	Adoption choice (*j*)							
	Non-adoption		Intensification		Sustainable		SI	
	Coef.	SE	Coef.	SE	Coef.	SE	Coef.	SE
Male-headed HH (yes = 1)	-0.01	0.14	0.55	0.42	-0.08	0.11	-0.23	0.32
Age of HH head (years)	-0.02	0.02	-0.10	0.11	0.03	0.03	-0.08	0.08
Education of HH head (years)	0.08***	0.02	0.12**	0.05	0.12***	0.02	0.08*	0.05
Family labor (number of adults per acre)	-0.07	0.06	0.11	0.25	0.02	0.06	-0.21	0.19
Total cultivated land (acres)	0.01	0.01	0.07	0.05	0.00	0.01	0.00	0.04
Off-farm income (yes = 1)	0.10	0.19	0.23	0.42	0.25	0.21	0.48	0.43
Farm assets (1,000 TZS)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Livestock ownership (yes = 1)	0.30**	0.13	0.76	0.46	0.47***	0.16	0.88***	0.29
Access to credit (yes = 1)	0.44**	0.21	0.10	0.51	0.22	0.18	-0.16	0.34
Membership (SACCOS) (yes = 1)	0.47**	0.24	0.46	0.57	0.99***	0.21	-0.01	0.35
Extension from gov't/NGO (yes = 1)	0.54***	0.18	0.03	0.34	0.05	0.17	0.31	0.30
Distance to main road (km)	0.00	0.00	-0.02*	0.01	0.00	0.00	-0.01	0.01
Distance to town (km)	0.00*	0.00	0.00	0.00	-0.01	0.00***	0.00	0.00
Distance to main market (km)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cooperatives (yes = 1)	-0.23**	0.11	0.20	0.30	0.05	0.12	-0.21	0.28
Input supplier (yes = 1)	-0.04	0.12	-0.50*	0.27	0.02	0.12	-0.13	0.26
Drought/Flood (yes = 1)	0.32*	0.17	-1.52**	0.63	0.12	0.15	-0.21	0.53
Crop disease/Pests (yes = 1)	0.52***	0.18	-0.62	0.49	-0.08	0.16	-0.45	0.33
Total rainfall (mm)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Soil nutrient constraint (yes = 1)	-0.03	0.09	0.09	0.36	0.12	0.12	0.16	0.33
Inorganic fertilizer price (TZS/kg)	0.00*	0.00	0.00*	0.00	0.00	0.00	0.00	0.00
Lagged price of maize (TZS/kg)	0.00	0.00	0.00	0.01	0.00*	0.00	0.00	0.00
Lagged price of rice (TZS/kg)	0.00	0.00	0.00	0.00	0.00**	0.00	0.00	0.00
Bean price (TZS/kg)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Groundnut price (TZS/kg)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 2A.13 (cont'd)

Variables	Adoption choice (j)							
	Non-adoption		Intensification		Sustainable		SI	
	Coef.	SE	Coef.	SE	Coef.	SE	Coef.	SE
Year dummy (2010/11)	-0.23	0.25	0.70	1.10	0.01	0.26	0.52	0.70
Year dummy (2012/13)	-0.31	0.26	0.76	0.80	-0.50**	0.25	0.62	0.58
T2 dummy	0.03	0.14	-0.38	0.55	0.01	0.13	0.53	0.49
T3 dummy	0.02	0.13	0.00	0.55	0.00	0.14	0.75*	0.45
Constant	8.06***	0.77	2.45	3.84	7.54***	0.93	8.31***	2.92
Joint significance of excluded IVs	F(3,1573)=1.45		F(3,196)=0.73		F(3,1396)=0.92		F(3,300)=1.47	
Joint significance of time-varying covariates	22.08**		10.81		12.55		12.52	
Ancillary								
σ^2	3.93***	1.34	3.52	5.43	3.58***	0.89	3.89	4.45
λ_1			0.45	0.55	-0.09	0.18	-0.46	0.56
λ_2	-0.41	0.59			0.45	0.54	-0.28	0.49
λ_3	-0.25	0.24	-0.72	0.70			0.66*	0.39
λ_4	0.58	0.55	0.22	0.60	-0.45	0.50		
Number of observations	1,617		240		1,440		344	

Notes: Non-adoption is the reference category. Standard errors were bootstrapped with 100 replications. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Table 2A.14: CRE-MESR second stage estimation results for food expenditure (1,000 TZS) per adult equivalent

Variables	Adoption choice (*j*)							
	Non-adoption		Intensification		Sustainable		SI	
	Coef.	SE	Coef.	SE	Coef.	SE	Coef.	SE
Male-headed HH (yes = 1)	-25.53	16.00	8.22	65.86	-29.55	19.68	-103.62*	57.72
Age of HH head (years)	-0.38	2.94	-31.68	33.20	4.31	3.50	5.79	9.93
Education of HH head (years)	6.13**	2.95	11.77	7.56	8.52***	2.38	11.46	9.26
Family labor (number of adults per acre)	-3.02	10.89	-56.75	37.62	-1.64	11.57	-38.88	29.68
Total cultivated land (acres)	1.64	1.79	-0.49	7.17	5.08	3.50	-0.32	4.18
Off-farm income (yes = 1)	42.72**	21.16	-39.94	65.14	29.68	29.48	-10.70	52.49
Farm assets (1,000 TZS)	0.00	0.00	-0.01	0.02	0.00	0.00	0.00	0.01
Livestock ownership (yes = 1)	30.88	19.43	75.44	63.55	-32.81*	18.84	57.65	40.04
Access to credit (yes = 1)	66.99*	35.03	-29.25	80.92	4.98	28.90	69.10	60.14
Membership (SACCOS) (yes = 1)	41.17	45.28	-70.33	75.89	94.81**	38.55	-60.22	63.68
Extension from gov't/NGO (yes = 1)	15.76	26.00	120.81**	55.77	51.61	32.44	74.75*	43.85
Distance to main road (km)	-0.08	0.37	0.93	1.66	0.12	0.33	-0.79	1.02
Distance to town (km)	-0.30	0.24	-0.32	0.77	-0.57**	0.25	-0.44	0.60
Distance to main market (km)	0.07	0.20	-0.54	0.45	0.18	0.18	0.00	0.46
Cooperatives (yes = 1)	-9.43	17.71	-5.09	52.35	5.53	16.09	-23.20	39.34
Input supplier (yes = 1)	-27.98*	15.50	-51.37	39.33	0.85	16.17	22.36	35.11
Drought/Flood (yes = 1)	23.06	22.99	-174.12*	90.17	10.46	27.18	-56.34	64.82
Crop disease/Pests (yes = 1)	19.09	26.64	17.24	71.12	10.64	28.63	-75.35	58.84
Total rainfall (mm)	0.00	0.06	-0.04	0.27	-0.02	0.08	0.27	0.19
Soil nutrient constraint (yes = 1)	-27.21*	14.71	81.32	51.16	-39.90**	18.95	35.12	44.92
Inorganic fertilizer price (TZS/kg)	-0.02	0.02	-0.12**	0.05	0.00	0.01	0.00	0.04
Lagged price of maize (TZS/kg)	-0.01	0.23	1.24	0.90	0.05	0.21	-0.63	0.62
Lagged price of rice (TZS/kg)	-0.04	0.09	-0.10	0.30	-0.06	0.10	-0.16	0.25
Bean price (TZS/kg)	-0.12	0.08	0.50	0.52	0.02	0.10	-0.04	0.26
Groundnut price (TZS/kg)	-0.03	0.04	-0.18	0.19	0.02	0.04	0.15	0.11

Table 2A.14 (cont'd)

Variables	Adoption choice (j)							
	Non-adoption		Intensification		Sustainable		SI	
	Coef.	SE	Coef.	SE	Coef.	SE	Coef.	SE
Year dummy (2010/11)	20.22	33.98	118.26	179.40	18.11	32.73	70.66	111.03
Year dummy (2012/13)	175.18***	29.04	215.43	161.03	153.35***	35.02	261.88***	100.10
T2 dummy	-51.14**	22.31	-20.20	94.65	-32.07	24.03	-41.99	87.60
T3 dummy	-72.15***	17.63	-139.47	90.01	-30.64	20.54	-61.44	90.68
Constant	158.10	120.98	246.39	775.50	186.55	153.97	118.60	491.70
Joint significance of excluded IVs	F(3,1573)=1.89		F(3,196)=0.04		F(3,1396)=0.49		F(3,300)=1.12	
Joint significance of time-varying covariates	31.34***		12.17		13.02		29.48***	
Ancillary								
σ^2	116,596**	51,518	59,725	114,432	109,321***	26,249	93,603	77,571
λ_1			-0.20	0.58	-0.18	0.18	0.25	0.64
λ_2	0.46	0.52			0.86*	0.52	-0.81	0.50
λ_3	0.55***	0.19	0.02	0.74			0.23	0.49
λ_4	-0.94**	0.46	0.30	0.57	-0.76*	0.43		
Number of observations	1,617		240		1,440		344	

Notes: Non-adoption is the reference category. Standard errors were bootstrapped with 100 replications. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Table 2A.15: CRE-MESR second stage estimation results for FCS

Variables	Adoption choice (*j*)							
	Non-adoption		Intensification		Sustainable		SI	
	Coef.	SE	Coef.	SE	Coef.	SE	Coef.	SE
Male-headed HH (yes = 1)	3.17**	1.51	1.43	6.84	-1.21	1.71	-3.53	4.86
Age of HH head (years)	-0.18	0.28	0.12	1.80	-0.16	0.35	0.35	3.73
Education of HH head (years)	0.20	0.22	1.25	0.94	0.95***	0.25	1.37*	0.73
Family labor (number of adults per acre)	-1.06	0.74	0.04	6.47	-0.29	0.52	-3.13	2.22
Total cultivated land (acres)	-0.05	0.16	-0.58	1.00	-0.10	0.22	-0.36	0.59
Off-farm income (yes = 1)	2.72	2.09	2.83	8.21	0.05	2.21	-1.61	4.88
Farm assets (1,000 TZS)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Livestock ownership (yes = 1)	4.80***	1.83	10.51	7.61	3.75*	2.05	6.80*	3.88
Access to credit (yes = 1)	3.58	3.17	2.72	10.13	0.32	3.41	1.46	4.01
Membership (SACCOS) (yes = 1)	1.19	3.19	-6.50	8.40	3.77	3.08	2.76	6.91
Extension from gov't/NGO (yes = 1)	3.57	2.95	-0.07	6.32	2.34	3.42	5.29	3.71
Distance to main road (km)	-0.02	0.03	-0.24	0.17	0.04	0.03	-0.15	0.09
Distance to town (km)	-0.04	0.03	0.00	0.08	-0.03	0.03	-0.07	0.06
Distance to main market (km)	0.03*	0.02	0.02	0.05	0.00	0.02	0.02	0.04
Cooperatives (yes = 1)	-2.71*	1.51	-0.98	5.34	3.32**	1.52	5.07	4.02
Input supplier (yes = 1)	0.67	1.47	-6.00	6.19	-1.37	1.73	-8.79***	2.91
Drought/Flood (yes = 1)	1.16	2.16	-11.07	10.16	0.94	2.35	3.69	6.76
Crop disease/Pests (yes = 1)	-0.60	1.99	-12.72	11.50	-3.97*	2.41	-0.44	6.79
Total rainfall (mm)	0.00	0.01	0.06	0.05	0.01	0.01	-0.01	0.02
Soil nutrient constraint (yes = 1)	-3.38**	1.39	-2.41	6.37	-4.61**	1.82	3.35	3.99
Inorganic fertilizer price (TZS/kg)	0.00	0.00	-0.01	0.01	0.00	0.00	0.00	0.00
Lagged price of maize (TZS/kg)	-0.04	0.03	-0.12	0.17	-0.01	0.03	-0.05	0.08
Lagged price of rice (TZS/kg)	0.02	0.01	0.00	0.03	0.01	0.01	-0.02	0.02
Bean price (TZS/kg)	-0.02	0.02	-0.04	0.08	0.01	0.02	-0.05	0.04
Groundnut price (TZS/kg)	0.00	0.01	0.01	0.03	0.00	0.01	0.01	0.02

Table 2A.15 (cont'd)

Variables	Adoption choice (j)							
	Non-adoption		Intensification		Sustainable		SI	
	Coef.	SE	Coef.	SE	Coef.	SE	Coef.	SE
Year dummy (2012/13)	-1.52	3.36	3.54	12.88	-2.15	3.07	0.19	12.87
Constant	17.36	12.37	-47.81	181.98	65.90***	18.22	-38.45	77.58
Joint significance of excluded IVs	F(3,667)=1.03		F(3,97)=1.10		F(3,550)=1.84		F(3,144)=0.38	
Joint significance of time-varying covariates	9.1		5.79		20.53**		12.70	
Ancillary								
σ^2	309.01*	163.71	545.01	1440.91	340.46***	92.94	192.24	469.31
λ_1			-0.82	0.63	0.01	0.28	-0.39	0.75
λ_2	0.38	0.58			0.89	0.59	0.21	0.64
λ_3	0.49	0.33	0.16	0.69			0.14	0.66
λ_4	-0.75	0.53	0.85	0.77	-0.70	0.50		
Number of observations	708		138		591		185	

Notes: Non-adoption is the reference category. Standard errors were bootstrapped with 100 replications. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Table 2A.16: Average treatment effects on the untreated (ATU) of using practices in each SI category on household net crop income, productivity and food access outcomes

Outcome variables	SI category	Adoption status		Average treatment effects
		Adopting ($j = 2, 3, 4$)	Nonadopting ($j = 1$)	
		(1)	(2)	(3) = (1) – (2)
Net crop income (1,000 TZS) (N=3,641)	Intensification	452.74 (22.47)	265.73 (4.60)	187.01*** (19.96)
	Sustainable	332.51 (7.47)	265.73 (4.60)	66.78*** (5.00)
	SI	492.46 (22.18)	265.73 (4.60)	226.73*** (19.71)
Net crop income (1,000 TZS) per acre (N=3,641)	Intensification	159.81 (2.94)	87.33 (0.87)	72.48*** (2.78)
	Sustainable	107.16 (1.00)	87.33 (0.87)	19.83*** (0.70)
	SI	115.85 (2.20)	87.33 (0.87)	28.52*** (2.15)
Net crop income (1,000 TZS) per adult equivalent (N=3,641)	Intensification	113.41 (4.29)	66.64 (0.79)	46.77*** (4.08)
	Sustainable	85.19 (1.10)	66.64 (0.79)	18.55*** (0.90)
	SI	104.12 (3.72)	66.64 (0.79)	37.48*** (3.47)
Crop productivity (N=3,641)	Intensification	716.82 (10.12)	316.54 (3.12)	400.28*** (9.57)
	Sustainable	390.70 (3.76)	316.54 (3.12)	74.16*** (2.53)
	SI	503.06 (8.81)	316.54 (3.12)	186.52*** (7.83)
Modified HDDS (N=3,641)	Intensification	8.36 (0.03)	7.68 (0.02)	0.68*** (0.03)
	Sustainable	7.79 (0.02)	7.68 (0.02)	0.11*** (0.01)
	SI	8.79 (0.03)	7.68 (0.02)	1.11*** (0.03)
Food expenditure (1,000 TZS) per adult equivalent (N=3,641)	Intensification	544.01 (6.11)	454.80 (2.92)	89.22*** (5.35)
	Sustainable	481.36 (2.44)	454.80 (2.92)	26.56*** (1.57)
	SI	628.48 (5.10)	454.80 (2.92)	173.68*** (4.36)
FCS (N=1,622)	Intensification	49.72 (0.72)	49.14 (0.24)	0.58 (0.64)
	Sustainable	50.95 (0.27)	49.14 (0.24)	1.81*** (0.21)
	SI	56.86 (0.59)	49.14 (0.24)	7.72*** (0.51)

Notes: Standard errors in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Table 2A.17: Average treatment effects of using practices in each SI category on household income, productivity, and food access outcomes (Unconditional average effects)

Outcome variables	SI category	Adoption status		Average treatment effects
		Adopting ($j = 2, 3, 4$)	Nonadopting ($j = 1$)	
		(1)	(2)	(3) = (1) – (2)
Net crop income (1,000 TZS) (N=3,641)	Intensification	426.88 (13.09)	265.94 (3.28)	160.94*** (12.42)
	Sustainable	342.54 (5.09)	265.94 (3.28)	76.60*** (3.16)
	SI	542.15 (15.28)	265.94 (3.28)	276.21*** (13.29)
Net crop income (1,000 TZS) per acre (N=3,641)	Intensification	142.77 (1.85)	83.47 (0.56)	59.30*** (1.75)
	Sustainable	106.63 (0.63)	83.47 (0.56)	23.16*** (0.48)
	SI	114.11 (1.58)	83.47 (0.56)	30.64*** (1.56)
Net crop income (1,000 TZS) per adult equivalent (N=3,641)	Intensification	103.81 (2.64)	63.93 (0.53)	39.88*** (2.49)
	Sustainable	83.11 (0.71)	63.93 (0.53)	19.18*** (0.59)
	SI	108.38 (2.39)	63.93 (0.53)	44.45*** (2.20)
Crop productivity (N=3,641)	Intensification	674.46 (6.44)	309.36 (2.04)	365.10*** (6.12)
	Sustainable	396.17 (2.40)	309.36 (2.04)	86.81*** (1.74)
	SI	532.60 (5.91)	309.36 (2.04)	223.24*** (5.25)
Modified HDDS (N=3,641)	Intensification	8.46 (0.02)	7.77 (0.01)	0.69*** (0.02)
	Sustainable	7.90 (0.01)	7.77 (0.01)	0.13*** (0.01)
	SI	8.73 (0.02)	7.77 (0.01)	0.96*** (0.02)
Food expenditure (1,000 TZS) per adult equivalent (N=3,641)	Intensification	535.36 (3.97)	467.96 (2.00)	67.40*** (3.54)
	Sustainable	486.41 (1.66)	467.96 (2.00)	18.45*** (1.06)
	SI	603.78 (3.52)	467.96 (2.00)	135.82*** (3.10)
FCS (N=1,622)	Intensification	49.58 (0.49)	49.93 (0.18)	-0.35 (0.43)
	Sustainable	51.19 (0.18)	49.93 (0.18)	1.26*** (0.15)
	SI	57.23 (0.41)	49.93 (0.18)	7.30*** (0.34)

Notes: Standard errors in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Table 2A.18: Marginal effects of use of practices in each SI category on net crop income (1,000 TZS)

Variables	Intensification		Sustainable		SI	
	dy/dx	SE	dy/dx	SE	dy/dx	SE
Male-headed HH (yes = 1)	0.008	0.011	0.004	0.019	-0.009	0.011
Age of HH head (years)	-0.002	0.002	0.005	0.004	0.002	0.002
Education of HH head (years)	0.004***	0.001	-0.003	0.003	0.006***	0.002
Family labor (number of adults per acre)	-0.008*	0.004	0.004	0.009	0.001	0.006
Total cultivated land (acres)	-0.001	0.001	0.001	0.002	-0.001	0.001
Off-farm income (yes = 1)	0.014	0.013	-0.008	0.028	-0.005	0.014
Farm assets (1,000 TZS)	-0.000	0.000	0.000	0.000	0.000	0.000
Livestock ownership (yes = 1)	-0.010	0.008	0.091***	0.017	0.045***	0.009
Access to credit (yes = 1)	0.012	0.012	-0.029	0.030	0.044***	0.014
Membership (SACCOS) (yes = 1)	0.027*	0.015	-0.021	0.040	0.027	0.017
Extension from gov't/NGO (yes = 1)	0.020*	0.010	-0.049*	0.029	0.041***	0.012
Distance to main road (km)	-0.000	0.000	-0.000	0.000	-0.001**	0.000
Distance to town (km)	-0.000**	0.000	-0.000	0.000	-0.000**	0.000
Distance to main market (km)	0.000**	0.000	0.000	0.000	0.000***	0.000
Cooperatives (yes = 1)	0.015*	0.008	-0.006	0.016	-0.018**	0.009
Input supplier (yes = 1)	0.003	0.008	-0.027	0.017	0.009	0.009
Drought/Flood (yes = 1)	0.002	0.015	0.007	0.024	-0.030*	0.018
Crop disease/Pests (yes = 1)	0.001	0.015	0.008	0.027	-0.003	0.016
Total rainfall (mm)	0.000	0.000	-0.000	0.000	-0.000	0.000
Soil nutrient constraint (yes = 1)	-0.011	0.009	0.013	0.017	0.015	0.011
Inorganic fertilizer price (TZS/kg)	0.000*	0.000	0.000	0.000	-0.000	0.000
Lagged price of maize (TZS/kg)	-0.000	0.000	0.000	0.000	0.000	0.000
Lagged price of rice (TZS/kg)	0.000	0.000	-0.000	0.000	-0.000	0.000
Bean price (TZS/kg)	-0.000	0.000	-0.000	0.000	0.000	0.000
Groundnut price (TZS/kg)	-0.000	0.000	0.000	0.000	-0.000	0.000
Year dummy (2010/11)	0.035	0.024	-0.047	0.041	0.019	0.027
Year dummy (2012/13)	0.054***	0.020	0.010	0.036	0.013	0.023
T2 dummy	0.002	0.012	-0.060***	0.021	0.028*	0.014
T3 dummy	0.002	0.012	-0.049**	0.021	0.017	0.014
Electoral threat	-0.026	0.024	-0.028	0.024	0.001	0.023
Proportion adopting inorganic fertilizer	0.001***	0.000	-0.001***	0.000	0.002***	0.000
Proportion adopting organic fertilizer	-0.000	0.000	0.001***	0.000	-0.000	0.000
Proportion adopting maize-legume IC	-0.000**	0.000	0.002***	0.000	0.000**	0.000

Notes: SE is standard errors. Non-adoption is the reference category. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Table 2A.19: Marginal effects of use of practices in each SI category on net crop income (1,000 TZS) per acre

Variables	Intensification		Sustainable		SI	
	dy/dx	SE	dy/dx	SE	dy/dx	SE
Male-headed HH (yes = 1)	0.008	0.011	0.002	0.019	-0.008	0.012
Age of HH head (years)	-0.002	0.002	0.005	0.004	0.002	0.002
Education of HH head (years)	0.004***	0.001	-0.003	0.003	0.006***	0.002
Family labor (number of adults per acre)	-0.008*	0.004	0.004	0.009	0.001	0.006
Total cultivated land (acres)	-0.001	0.001	0.001	0.002	-0.001	0.001
Off-farm income (yes = 1)	0.014	0.013	-0.007	0.028	-0.005	0.014
Farm assets (1,000 TZS)	-0.000	0.000	0.000	0.000	0.000	0.000
Livestock ownership (yes = 1)	-0.010	0.008	0.102***	0.016	0.044***	0.009
Access to credit (yes = 1)	0.012	0.012	-0.028	0.030	0.044***	0.014
Membership (SACCOS) (yes = 1)	0.027*	0.015	-0.024	0.040	0.027	0.017
Extension from gov’t/NGO (yes = 1)	0.019*	0.011	-0.045	0.029	0.040***	0.012
Distance to main road (km)	-0.000	0.000	-0.000	0.000	-0.001**	0.000
Distance to town (km)	-0.000**	0.000	-0.000	0.000	-0.000**	0.000
Distance to main market (km)	0.000**	0.000	0.000	0.000	0.000***	0.000
Cooperatives (yes = 1)	0.015*	0.008	-0.006	0.017	-0.018*	0.009
Input supplier (yes = 1)	0.004	0.008	-0.025	0.017	0.008	0.009
Drought/Flood (yes = 1)	0.002	0.015	0.005	0.024	-0.030*	0.018
Crop disease/Pests (yes = 1)	0.000	0.015	0.008	0.027	-0.003	0.016
Total rainfall (mm)	0.000	0.000	-0.000	0.000	-0.000	0.000
Soil nutrient constraint (yes = 1)	-0.011	0.009	0.010	0.017	0.015	0.011
Inorganic fertilizer price (TZS/kg)	0.000*	0.000	0.000	0.000	-0.000	0.000
Lagged price of maize (TZS/kg)	-0.000	0.000	0.000	0.000	0.000	0.000
Lagged price of rice (TZS/kg)	0.000	0.000	-0.000	0.000	-0.000	0.000
Bean price (TZS/kg)	-0.000	0.000	-0.000	0.000	0.000	0.000
Groundnut price (TZS/kg)	-0.000	0.000	0.000	0.000	-0.000	0.000
Year dummy (2010/11)	0.036	0.025	-0.063	0.041	0.023	0.027
Year dummy (2012/13)	0.056***	0.021	-0.001	0.036	0.017	0.023
T2 dummy	0.002	0.012	-0.057***	0.021	0.028*	0.014
T3 dummy	0.002	0.012	-0.046**	0.021	0.017	0.014
Electoral threat	-0.026	0.024	-0.029	0.024	0.001	0.023
Proportion receiving agricultural advice	0.000	0.000	-0.000	0.001	0.000	0.000
Proportion adopting inorganic fertilizer	0.001***	0.000	-0.001*	0.000	0.002***	0.000
Proportion adopting maize-legume IC	0.000**	0.000	0.003***	0.000	0.000**	0.000

Notes: SE is standard errors. Non-adoption is the reference category. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Table 2A.20: Marginal effects of use of practices in each SI category on net crop income (1,000 TZS) per adult equivalent

Variables	Intensification		Sustainable		SI	
	dy/dx	SE	dy/dx	SE	dy/dx	SE
Male-headed HH (yes = 1)	0.009	0.011	0.002	0.019	-0.006	0.011
Age of HH head (years)	-0.002	0.002	0.005	0.004	0.002	0.002
Education of HH head (years)	0.004***	0.001	-0.003	0.003	0.006***	0.002
Family labor (number of adults per acre)	-0.008*	0.004	0.003	0.009	0.002	0.006
Total cultivated land (acres)	-0.000	0.001	0.001	0.002	-0.001	0.001
Off-farm income (yes = 1)	0.013	0.013	-0.009	0.028	-0.004	0.014
Farm assets (1,000 TZS)	-0.000	0.000	0.000	0.000	0.000	0.000
Livestock ownership (yes = 1)	-0.011	0.008	0.093***	0.017	0.044***	0.009
Access to credit (yes = 1)	0.013	0.013	-0.030	0.030	0.046***	0.013
Membership (SACCOS) (yes = 1)	0.026*	0.015	-0.020	0.040	0.026	0.017
Extension from gov't/NGO (yes = 1)	0.019*	0.010	-0.047*	0.029	0.039***	0.012
Distance to main road (km)	-0.000	0.000	-0.000	0.000	-0.000	0.000
Distance to town (km)	-0.000**	0.000	-0.000	0.000	-0.000*	0.000
Distance to main market (km)	0.000**	0.000	0.000	0.000	0.000***	0.000
Cooperatives (yes = 1)	0.017**	0.008	-0.010	0.017	-0.016*	0.009
Input supplier (yes = 1)	0.002	0.008	-0.022	0.017	0.003	0.009
Drought/Flood (yes = 1)	0.003	0.015	0.005	0.024	-0.028	0.018
Crop disease/Pests (yes = 1)	0.001	0.015	0.007	0.027	-0.002	0.016
Total rainfall (mm)	0.000	0.000	-0.000	0.000	-0.000	0.000
Soil nutrient constraint (yes = 1)	-0.007	0.009	0.003	0.018	0.025**	0.011
Inorganic fertilizer price (TZS/kg)	0.000*	0.000	0.000	0.000	-0.000	0.000
Lagged price of maize (TZS/kg)	-0.000	0.000	0.000	0.000	0.000	0.000
Lagged price of rice (TZS/kg)	-0.000	0.000	-0.000	0.000	-0.000*	0.000
Bean price (TZS/kg)	-0.000	0.000	-0.000	0.000	0.000	0.000
Groundnut price (TZS/kg)	-0.000	0.000	0.000	0.000	-0.000	0.000
Year dummy (2010/11)	0.026	0.026	-0.021	0.042	-0.007	0.028
Year dummy (2012/13)	0.058***	0.021	0.001	0.036	0.026	0.023
T2 dummy	0.001	0.012	-0.059***	0.021	0.028**	0.014
T3 dummy	0.001	0.012	-0.047**	0.021	0.016	0.014
Electoral threat	-0.024	0.024	-0.032	0.024	0.004	0.022
Number of subsidized fertilizer vouchers	0.000	0.000	-0.000**	0.000	0.000***	0.000
Proportion adopting inorganic fertilizer	0.001***	0.000	-0.001**	0.000	0.002***	0.000
Proportion adopting organic fertilizer	-0.000	0.000	0.001***	0.000	-0.000	0.000
Proportion adopting maize-legume IC	-0.000**	0.000	0.003***	0.000	0.000*	0.000

Notes: SE is standard errors. Non-adoption is the reference category. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Table 2A.21: Marginal effects of use of practices in each SI category on crop productivity

Variables	Intensification		Sustainable		SI	
	dy/dx	SE	dy/dx	SE	dy/dx	SE
Male-headed HH (yes = 1)	0.010	0.011	0.001	0.019	-0.004	0.012
Age of HH head (years)	-0.002	0.002	0.005	0.004	0.002	0.002
Education of HH head (years)	0.006***	0.001	-0.005*	0.003	0.008***	0.002
Family labor (number of adults per acre)	-0.007	0.004	0.003	0.009	0.002	0.006
Total cultivated land (acres)	-0.001	0.001	0.001	0.002	-0.002	0.001
Off-farm income (yes = 1)	0.014	0.013	-0.006	0.028	-0.008	0.015
Farm assets (1,000 TZS)	-0.000	0.000	0.000	0.000	0.000	0.000
Livestock ownership (yes = 1)	-0.010	0.009	0.086***	0.017	0.050***	0.010
Access to credit (yes = 1)	0.020	0.013	-0.034	0.030	0.052***	0.014
Membership (SACCOS) (yes = 1)	0.045***	0.015	-0.031	0.040	0.041**	0.018
Extension from gov't/NGO (yes = 1)	0.026**	0.011	-0.053*	0.029	0.052***	0.012
Distance to main road (km)	-0.000	0.000	-0.000	0.000	-0.001***	0.000
Distance to town (km)	-0.001***	0.000	0.000	0.000	-0.001***	0.000
Distance to main market (km)	0.000***	0.000	0.000	0.000	0.001***	0.000
Cooperatives (yes = 1)	0.024***	0.008	-0.012	0.017	-0.006	0.010
Input supplier (yes = 1)	0.017**	0.008	-0.042**	0.017	0.031***	0.009
Drought/Flood (yes = 1)	0.000	0.015	0.008	0.025	-0.036*	0.019
Crop disease/Pests (yes = 1)	0.000	0.015	0.007	0.028	-0.001	0.017
Total rainfall (mm)	0.000	0.000	-0.000	0.000	0.000	0.000
Soil nutrient constraint (yes = 1)	-0.014	0.009	0.019	0.018	0.007	0.011
Inorganic fertilizer price (TZS/kg)	0.000*	0.000	0.000	0.000	-0.000	0.000
Lagged price of maize (TZS/kg)	-0.000	0.000	0.000	0.000	-0.000	0.000
Lagged price of rice (TZS/kg)	0.000	0.000	-0.000	0.000	-0.000	0.000
Bean price (TZS/kg)	-0.000	0.000	-0.000	0.000	0.000	0.000
Groundnut price (TZS/kg)	-0.000	0.000	0.000	0.000	-0.000	0.000
Year dummy (2010/11)	0.061**	0.025	-0.079*	0.041	0.059**	0.028
Year dummy (2012/13)	0.077***	0.021	-0.019	0.037	0.049**	0.023
T2 dummy	0.006	0.013	-0.059***	0.021	0.024	0.015
T3 dummy	0.010	0.012	-0.055***	0.021	0.022	0.014
Electoral threat	-0.024	0.023	-0.032	0.024	0.001	0.020
Proportion receiving agricultural advice	0.001***	0.000	-0.002***	0.000	0.002***	0.000
Proportion adopting organic fertilizer	0.000**	0.000	0.001***	0.000	0.000**	0.000
Proportion adopting maize-legume IC	-0.000	0.000	0.002***	0.000	0.001***	0.000

Notes: SE is standard errors. Non-adoption is the reference category. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Table 2A.22: Marginal effects of use of practices in each SI category on modified HDDS

Variables	Intensification		Sustainable		SI	
	dy/dx	SE	dy/dx	SE	dy/dx	SE
Male-headed HH (yes = 1)	0.008	0.011	0.002	0.019	-0.009	0.011
Age of HH head (years)	-0.002	0.002	0.005	0.004	0.002	0.002
Education of HH head (years)	0.004***	0.001	-0.003	0.003	0.006***	0.002
Family labor (number of adults per acre)	-0.008*	0.004	0.004	0.009	0.001	0.006
Total cultivated land (acres)	-0.000	0.001	0.001	0.002	-0.001	0.001
Off-farm income (yes = 1)	0.014	0.013	-0.007	0.028	-0.005	0.014
Farm assets (1,000 TZS)	-0.000	0.000	0.000	0.000	0.000	0.000
Livestock ownership (yes = 1)	-0.010	0.008	0.102***	0.016	0.044***	0.009
Access to credit (yes = 1)	0.012	0.012	-0.029	0.030	0.044***	0.014
Membership (SACCOS) (yes = 1)	0.027*	0.015	-0.023	0.040	0.027	0.017
Extension from gov’t/NGO (yes = 1)	0.020*	0.010	-0.047	0.029	0.041***	0.012
Distance to main road (km)	-0.000	0.000	-0.000	0.000	-0.001**	0.000
Distance to town (km)	-0.000**	0.000	-0.000	0.000	-0.000**	0.000
Distance to main market (km)	0.000**	0.000	0.000	0.000	0.000***	0.000
Cooperatives (yes = 1)	0.015*	0.008	-0.007	0.017	-0.018*	0.009
Input supplier (yes = 1)	0.003	0.008	-0.025	0.017	0.008	0.009
Drought/Flood (yes = 1)	0.002	0.015	0.005	0.024	-0.030*	0.018
Crop disease/Pests (yes = 1)	0.001	0.015	0.007	0.027	-0.003	0.016
Total rainfall (mm)	0.000	0.000	-0.000	0.000	-0.000	0.000
Soil nutrient constraint (yes = 1)	-0.011	0.009	0.010	0.017	0.015	0.011
Inorganic fertilizer price (TZS/kg)	0.000*	0.000	0.000	0.000	-0.000	0.000
Lagged price of maize (TZS/kg)	-0.000	0.000	0.000	0.000	0.000	0.000
Lagged price of rice (TZS/kg)	0.000	0.000	-0.000	0.000	-0.000	0.000
Bean price (TZS/kg)	-0.000	0.000	-0.000	0.000	0.000	0.000
Groundnut price (TZS/kg)	-0.000	0.000	0.000	0.000	-0.000	0.000
Year dummy (2010/11)	0.035	0.024	-0.058	0.041	0.021	0.027
Year dummy (2012/13)	0.054***	0.020	0.004	0.036	0.015	0.022
T2 dummy	0.002	0.012	-0.057***	0.021	0.028*	0.014
T3 dummy	0.002	0.012	-0.046**	0.021	0.017	0.014
Electoral threat	-0.026	0.024	-0.028	0.024	0.001	0.023
Proportion adopting inorganic fertilizer	0.001***	0.000	-0.001**	0.000	0.002***	0.000
Proportion adopting maize-legume IC	-0.000**	0.000	0.003***	0.000	0.000**	0.000

Notes: SE is standard errors. Non-adoption is the reference category. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Table 2A.23: Marginal effects of use of practices in each SI category on food expenditure per adult equivalent

Variables	Intensification		Sustainable		SI	
	dy/dx	SE	dy/dx	SE	dy/dx	SE
Male-headed HH (yes = 1)	0.008	0.011	0.002	0.019	-0.009	0.011
Age of HH head (years)	-0.002	0.002	0.005	0.004	0.002	0.002
Education of HH head (years)	0.004***	0.001	-0.003	0.003	0.006***	0.002
Family labor (number of adults per acre)	-0.008*	0.004	0.004	0.009	0.001	0.006
Total cultivated land (acres)	-0.000	0.001	0.001	0.002	-0.001	0.001
Off-farm income (yes = 1)	0.013	0.013	-0.009	0.028	-0.005	0.014
Farm assets (1,000 TZS)	-0.000	0.000	0.000	0.000	0.000	0.000
Livestock ownership (yes = 1)	-0.010	0.008	0.092***	0.017	0.045***	0.009
Access to credit (yes = 1)	0.013	0.012	-0.028	0.030	0.045***	0.014
Membership (SACCOS) (yes = 1)	0.026*	0.015	-0.023	0.040	0.027	0.017
Extension from gov't/NGO (yes = 1)	0.020*	0.010	-0.048*	0.029	0.041***	0.012
Distance to main road (km)	-0.000	0.000	-0.000	0.000	-0.001**	0.000
Distance to town (km)	-0.000**	0.000	0.000	0.000	-0.000**	0.000
Distance to main market (km)	0.000**	0.000	0.000	0.000	0.000***	0.000
Cooperatives (yes = 1)	0.015*	0.008	-0.008	0.016	-0.019**	0.009
Input supplier (yes = 1)	0.004	0.008	-0.030*	0.017	0.009	0.009
Drought/Flood (yes = 1)	0.002	0.015	0.009	0.024	-0.030*	0.018
Crop disease/Pests (yes = 1)	0.001	0.015	0.009	0.027	-0.003	0.016
Total rainfall (mm)	0.000	0.000	-0.000	0.000	-0.000	0.000
Soil nutrient constraint (yes = 1)	-0.010	0.009	0.015	0.017	0.015	0.011
Inorganic fertilizer price (TZS/kg)	0.000*	0.000	0.000	0.000	-0.000	0.000
Lagged price of maize (TZS/kg)	-0.000	0.000	0.000	0.000	0.000	0.000
Lagged price of rice (TZS/kg)	0.000	0.000	-0.000	0.000	-0.000	0.000
Bean price (TZS/kg)	-0.000	0.000	-0.000	0.000	0.000	0.000
Groundnut price (TZS/kg)	-0.000	0.000	0.000	0.000	-0.000	0.000
Year dummy (2010/11)	0.035	0.024	-0.034	0.040	0.020	0.027
Year dummy (2012/13)	0.052***	0.020	0.015	0.036	0.013	0.022
T2 dummy	0.002	0.012	-0.060***	0.021	0.028*	0.014
T3 dummy	0.002	0.012	-0.049**	0.021	0.017	0.014
Proportion adopting inorganic fertilizer	0.001***	0.000	-0.001***	0.000	0.002***	0.000
Proportion adopting organic fertilizer	-0.000	0.000	0.001***	0.000	-0.000	0.000
Proportion adopting maize-legume IC	-0.000**	0.000	0.003***	0.000	0.000**	0.000

Notes: SE is standard errors. Non-adoption is the reference category. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Table 2A.24: Marginal effects of use of practices in each SI category on FCS

Variables	Intensification		Sustainable		SI	
	dy/dx	SE	dy/dx	SE	dy/dx	SE
Male-headed HH (yes = 1)	-0.017	0.017	0.006	0.029	0.002	0.019
Age of HH head (years)	-0.004	0.004	0.012**	0.006	0.005	0.004
Education of HH head (years)	0.003	0.002	-0.000	0.004	0.008***	0.003
Family labor (number of adults per acre)	-0.006	0.012	-0.008	0.010	0.008	0.009
Total cultivated land (acres)	-0.001	0.002	0.001	0.003	-0.000	0.002
Off-farm income (yes = 1)	0.016	0.023	0.007	0.038	0.004	0.025
Farm assets (1,000 TZS)	-0.000	0.000	0.000	0.000	0.000	0.000
Livestock ownership (yes = 1)	-0.010	0.014	0.096***	0.025	0.047***	0.015
Access to credit (yes = 1)	0.008	0.022	-0.055	0.046	0.059***	0.023
Membership (SACCOS) (yes = 1)	0.041*	0.025	-0.059	0.055	0.018	0.028
Extension from gov’t/NGO (yes = 1)	0.037**	0.018	-0.081*	0.048	0.035*	0.019
Distance to main road (km)	-0.000	0.000	-0.001*	0.001	-0.000	0.000
Distance to town (km)	-0.000	0.000	0.000	0.000	-0.000	0.000
Distance to main market (km)	0.000**	0.000	0.000	0.000	0.000*	0.000
Cooperatives (yes = 1)	0.025*	0.014	-0.036	0.025	-0.024	0.016
Input supplier (yes = 1)	0.006	0.014	-0.016	0.026	-0.008	0.015
Drought/Flood (yes = 1)	0.030	0.023	0.029	0.036	-0.039	0.031
Crop disease/Pests (yes = 1)	-0.015	0.028	-0.041	0.043	-0.013	0.028
Total rainfall (mm)	0.000*	0.000	-0.000**	0.000	-0.000	0.000
Soil nutrient constraint (yes = 1)	-0.003	0.017	0.013	0.028	0.027	0.019
Inorganic fertilizer price (TZS/kg)	-0.000	0.000	0.000	0.000	-0.000	0.000
Lagged price of maize (TZS/kg)	-0.000	0.000	0.001**	0.000	0.001*	0.000
Lagged price of rice (TZS/kg)	-0.000	0.000	-0.000*	0.000	-0.000**	0.000
Bean price (TZS/kg)	-0.000	0.000	0.000	0.000	0.000	0.000
Groundnut price (TZS/kg)	-0.000	0.000	-0.000	0.000	-0.000	0.000
Year dummy (2012/13)	0.007	0.036	0.032	0.056	0.067*	0.039
Number of subsidized fertilizer vouchers	0.000	0.000	-0.000	0.000	0.000***	0.000
Proportion adopting inorganic fertilizer	0.002***	0.000	-0.001**	0.000	0.002***	0.000
Proportion adopting maize-legume IC	-0.000	0.000	0.002***	0.000	0.000	0.000

Notes: SE is standard errors. Non-adoption is the reference category. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

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CHAPTER 3

THE EFFECTS OF THE NATIONAL AGRICULTURAL INPUT VOUCHER SCHEME (NAIVS) ON SUSTAINABLE INTENSIFICATION OF MAIZE PRODUCTION IN TANZANIA

3.1 Introduction

Hunger and food insecurity continue to be major challenges in sub-Saharan Africa (SSA). Currently, SSA is the region with the largest gap between cereal consumption and production and about a quarter of the population suffered from chronic food deprivation in 2017 (van Ittersum et al., 2016; FAO, IFAD, UNICEF, WFP and WHO, 2018). These problems may become more serious in the future because by 2050 the population in SSA is projected to increase 2.5-fold and its cereal demand is projected to triple, while the region already imports substantial quantities of cereals to meet current demand (van Ittersum et al., 2016). In addition, there is an emerging consensus that conventional intensification of agricultural systems involving the use of inorganic fertilizer and high-yielding crop varieties may be insufficient to sustainably intensify agricultural production and that conventional intensification can have negative environmental externalities (Petersen and Snapp, 2015; Pingali, 2012). In this context, sustainable intensification (SI) has been identified as a potential means to feed an increasing global population and meet rising food demand (Godfray et al., 2010). The main goal of SI is to produce more agricultural output from the same area of land (or less land) on a sustainable basis without adverse environmental impact (Pretty et al., 2011; The Montpellier Panel, 2013). While SI does not refer to a specific set of agricultural inputs or management practices and there are likely to be many pathways to SI, Holden (2018) points to integrated soil fertility management (ISFM) and conservation agriculture (CA) as two potential approaches to SI. ISFM is defined as the combined use of inorganic fertilizer and locally available soil amendments and organic matter, whereas CA involves crop rotation/intercropping with legumes, permanent soil coverage, and minimum soil disturbance.

Nonetheless, many African governments' policies aimed at increasing agricultural productivity have primarily focused on conventional intensification – in particular, trying to raise smallholder farmers' use of inorganic fertilizer and improved maize and rice varieties through large scale input subsidy programs (ISPs). In recent years, 10 African countries spent approximately US$0.6-1 billion annually on ISPs. But despite the heavy spending on the programs, the effects of ISPs on crop production and productivity as well as incomes and poverty have generally been smaller than anticipated (Jayne et al., 2018). In a review paper on Africa's ISPs, Jayne et al. (2018) argue that low crop yield response to inorganic fertilizer consistently reduces the productivity effects of ISPs. In particular, poor soil quality (e.g., low soil organic matter (SOM) and high soil acidity on many smallholders' fields) is a leading cause of low crop yield response to inorganic fertilizer application (Marenya and Barrett, 2009; Burke et al., 2017). It is therefore important to address poor soil quality issues (e.g., through an application of complementary soil fertility management (SFM) practices) in order to improve the agronomic efficiency of inorganic fertilizer use as well as ISPs' effectiveness (Holden, 2018; Jayne et al., 2018).

In recognition of the importance of integrated agricultural practices that improve soil health and the efficiency of inorganic fertilizer use, contribute to SI of agricultural systems, and have implications for the effectiveness of ISPs, the main research question of this study is whether ISPs encourage or discourage farmers' *joint use* of inorganic fertilizer with other SFM practices; this joint use can be considered a form of SI. To our knowledge, there have been no previous studies on this relationship. Instead, there have been only a few empirical studies on the effects of ISPs on farmers' use of *individual* SFM practices other than inorganic fertilizer in Malawi (Holden and Lunduka, 2012; Kassie et al., 2015a; Koppmair et al., 2017) and Zambia (Morgan et al., 2019). This is in contrast to the larger literature on the effects of ISPs on inorganic fertilizer purchases or use, which does not consider the programs' effects on other SFM practices or joint use of inorganic fertilizer with practices. (See Jayne et al. (2013) and Jayne et al. (2018) for listings and syntheses of these studies.)

We focus here on the case of Tanzania and the ISP implemented by the Government of Tanzania from 2008/09 through 2013/14: the National Agricultural Input Voucher Scheme (NAIVS). NAIVS provided targeted beneficiaries with vouchers for inorganic fertilizer and seed for improved varieties of maize or rice – two major staple crops in Tanzania. NAIVS is a "second-generation" ISP and a key example of a "market-smart" subsidy program designed to overcome the shortcomings of past programs including their limited impacts on productivity, high costs (and low benefit-cost ratios), politicization, and sidelining of the private sector (Jayne et al., 2018; Dorward, 2009; Morris et al., 2007; Pan and Christiaensen, 2012).[45] Tanzania's NAIVS is an important case study on this topic because it is widely considered to be the most private sector-friendly ISP in SSA to date (Wanzala et al., 2013). NAIVS was implemented through vouchers redeemable at private agro-dealers' shops whereas the above-mentioned studies on the effects of Malawi's and Zambia's ISPs on individual SFM practices cover periods when those countries' programs distributed subsidized fertilizer through government parastatals

[45] Most first generation ISPs were phased out in the 1990s, and second generation ISPs began being introduced in the early-mid 2000s (Jayne et al., 2018). Morris et al. (2007) provide 10 guiding principles to be a 'market-smart' ISP and Pan and Christiaensen (2012) briefly define such ISPs as follows: ISPs "are 'market-smart' if they are part of a broader productivity enhancement program, if they have a clear exit strategy, and most importantly, if they are carefully targeted at helping agents overcome market failures" (p. 1619).

(Malawi) or farmer cooperatives (Zambia) and not through the private sector (Mason and Ricker-Gilbert, 2013). Thus, the effects of NAIVS on farmers' use of SFM practices may differ from the effects in Malawi and Zambia. Furthermore, the design and implementation of ISPs varies across countries and time, so insights from a new country (in this case, Tanzania) can also help deepen our understanding of how ISP effects on farmers' use of SFM practices may vary depending on differences in program design and implementation.

This study focuses on SFM practices for maize production because maize is both the main staple food cultivated by the majority of Tanzanian smallholders and the main crop promoted through NAIVS (World Bank, 2004). The SFM practices considered here include the use of inorganic fertilizer, organic fertilizer such as animal manure or compost, and maize-legume intercropping. We focus on these three because they are the main SFM practices used by maize growing households in rural Tanzania. We follow Kim et al. (in press) and group the eight possible combinations of use of these three SFM practices into four "SI categories": i) "Non-adoption", meaning none of the practices are used; ii) "Intensification" to denote inorganic fertilizer use only; iii) "Sustainable", meaning use of organic fertilizer, maize-legume intercropping, or both; and iv) "SI" meaning joint use of inorganic fertilizer with at least one of the practices in the "Sustainable" category. Using nationally representative household panel survey data from Tanzania (the Tanzania National Panel Survey (TNPS) of 2008/09 and 2012/13), we estimate the impacts of receipt of vouchers for inorganic fertilizer and/or maize seed through NAIVS on farmers' use of the four categories defined above. The models are estimated using a multinomial logit (MNL) model combined with correlated random effects (CRE) and the control function (CF) approach to control, respectively, for time-invariant and time-varying unobserved heterogeneity that could be correlated with farmers' SI category decisions and their receipt of NAIVS vouchers.

This study contributes to the literature in several ways beyond being the first analysis of an SSA ISP's effects on farmers' *joint use* of inorganic fertilizer and complementary SFM practices. First, unlike several of the previous studies in the ISP-SFM literature that did not use nationally representative data (Holden and Lunduka, 2012; Kassie et al., 2015a; Koppmair et al., 2017) or used cross-sectional data (Kassie et al., 2015a), this study uses nationally representative household panel survey data. By using panel data methods, the internal validity of our results should be enhanced as we can control for time-invariant unobserved heterogeneity. Also, external validity should be improved by using the nationally-representative data. Second, we use the CF approach to address potential correlation of receipt of subsidized inputs with time-varying unobserved heterogeneity; in contrast, Kassie et al. (2015a) and Koppmair et al. (2017) do not directly address this issue, which may result in biased and inconsistent estimates.

We find statistically significant positive effects of household receipt of a NAIVS voucher for inorganic fertilizer on maize-growing households' use of inorganic fertilizer only (i.e., "Intensification"): the probability of using inorganic fertilizer only is on average 10.0 percentage points higher than for households who do not receive a NAIVS voucher. Our results further suggest that NAIVS voucher receipt encourages farmers to use inorganic fertilizer jointly with organic fertilizer and/or maize-legume intercropping. More specifically, NAIVS voucher receipt for inorganic fertilizer is associated with a 9.6 percentage point increase in a household's probability of using practices in the "SI" group. On the other hand, no such effects are found for the practices in the "Sustainable" group. In addition, receipt of a NAIVS voucher for maize seed has no statistically significant effect on farmers' SI category decisions.

The remainder of this study is organized as follows. First, we provide background information on the NAIVS program and SI of maize production in Tanzania. Next, we outline the conceptual framework and empirical strategies for estimating the effects of the NAIVS program on a maize-growing household's decision to use various SI categories, including joint use of inorganic fertilizer with other SFM practices. Then, we describe the data and variable specifications. Finally, we present our results and conclude by discussing policy implications.

3.2 Background: SI of maize production & the NAIVS program in Tanzania

3.2.1 SI of maize production in Tanzania

Per Kim et al. (in press), the main rationale for the categorization of inorganic fertilizer use only as "Intensification" but not "SI" is that although use of inorganic fertilizer has substantially contributed to raising agricultural productivity over the last several decades (Godfray et al., 2010; Pingali, 2012), its sole use can have adverse consequences including over-reliance on fossil fuels; decreases in biodiversity; ground and water pollution; and reductions in soil pH, soil organic carbon (SOC), soil aggregation, and microbial communities (Matson et al., 1997; Pingali, 2012; Petersen and Snapp, 2015; Bronick and Lal, 2005). Organic fertilizer use and maize-legume intercropping are considered "Sustainable" practices but not "SI" because they are local and renewable ways to raise soil fertility but their use without inorganic fertilizer is unlikely to significantly raise maize yields. Finally, the combined use of inorganic fertilizer with either organic fertilizer and/or maize-legume intercropping is considered "SI" because it is expected to result in sustainable increases in maize yields from the same area of the land while preserving or improving soil health due to the synergistic effects of joint use of the practices. See

Kim et al. (in press) for a much more detailed discussion of the rationale for these categorizations, including extensive references to the agronomy and other related literatures.

Table 3.1 shows the prevalence of the various SFM practices and SI categories on maize plots in Tanzania. Out of 2,559 maize plots in the sample (TNPS 2008/09 and 2012/13, described below), 41.4% of them are cultivated with only one of the three SFM practices. The maize plots with inorganic fertilizer only and organic fertilizer only account for 8.8% (case 2) and 6.5% (case 3) of all maize plots, respectively; and the maize plots intercropped with legumes but without use of the other two practices account for 26.1% (case 4). On the other hand, the proportion of maize plots cultivated with two or more SFM practices is relatively low, accounting for 13.3% of total maize plots (i.e., cases 5, 6, 7, and 8). Table 3.1 also shows the plot-level SI categories used for the empirical analysis: out of 2,559 maize plots, the "Sustainable" group accounts for 37% , while the "Intensification" and "SI" categories account for much lower proportions at approximately 9% of maize plots each. In particular, among the maize plots included in the "SI" group, the combined use of inorganic fertilizer and at least maize-legume intercropping accounts for 6.9%, while joint use of inorganic fertilizer and at least organic fertilizer is less prevalent. The remaining 45% of maize plots fall in the "Non-adoption" category. Among the three SFM practices, maize-legume intercropping is the most common among maize-growing households in rural Tanzania as it is used on 38% of all maize plots in the sample (alone or in combination with other practices). Inorganic fertilizer use and organic fertilizer use are much lower at 18% and 14% of maize plots, respectively (Table 3.1).

Table 3.1: SI of maize production categories and prevalence on maize plots in the sample

Case	Inorganic fertilizer	Organic fertilizer	Maize-legume intercropping	No. of maize plots (%)	SI category	No. of maize plots (%)
1				1,159 (45.3)	Non-adoption	1,159 (45.3)
2	√			224 (8.8)	Intensification	224 (8.8)
3		√		166 (6.5)	Sustainable	948 (37.0)
4			√	669 (26.1)		
5		√	√	113 (4.4)		
6	√	√		50 (2.0)	SI	228 (8.9)
7	√		√	147 (5.7)		
8	√	√	√	31 (1.2)		
Total number of maize plots				2,559 (100.0)		2,559 (100.0)
Use of inorganic fertilizer				452 (17.7)		
Use of organic fertilizer				360 (14.1)		
Use of maize-legume intercropping				960 (37.5)		

Note: Figures in the table are based on maize plots (*n*=2,559) cultivated by the balanced panel of rural maize-growing households across two waves of the TNPS (2008/09, and 2012/13). The eight cases and SI categories are each mutually exclusive, while the number of maize plots for the practices listed at the bottom of the table include maize plots for which the practice was applied alone or in combination with other practices. The legume crops reported as being intercropped with maize in the survey are beans, soybeans, groundnuts, cowpeas, pigeon peas, chickpeas, field peas, green grams, bambara nuts, and fiwi.
Source: Authors' calculations.

3.2.2 The National Agricultural Input Voucher Scheme

In Tanzania, there were large-scale, universal subsidy programs between the 1960s and the 1980s, where the government controlled importation and distribution of agricultural inputs and heavily subsidized input prices (World Bank, 2014). With the economic crisis in the mid-1980s that resulted in an economic reform program, the Tanzanian government greatly reduced subsidy rates on fertilizer from 80% in 1990 to 55% in early 1992, and to no more than 20% by mid-1992 (Putterman, 1995). These subsidies were ultimately phased out altogether after liberalization of agricultural markets between 1991 and 1994. In 2003, after a decade with no subsidized agricultural inputs, the Government of Tanzania resumed a transport subsidy for companies that were involved in the distribution of fertilizers. However, the transport subsidy was not successful since the distributors and agro-dealers who directly received the subsidy did not pass on the cost savings to smallholder farmers (Mather et al., 2016). Also, there were some constraints frequently reported under this system: delayed input delivery, inputs not being effective due to quality deterioration, and smuggling to neighboring countries (Aloyce et al., 2014). Eventually, due to concerns regarding the cost effectiveness of the program, targeting, and the distribution of subsidy benefits, the program was phased out and redesigned in 2007.

Following the 2007/2008 food price crisis, the Government of Tanzania decided to launch a voucher-based input subsidy program that was piloted in two districts within the Mbeya and Rukwa regions in 2007/08. The Tanzanian government with financial support from the World Bank in 2008/09 rapidly scaled up the existing input voucher pilot program with the goal of enhancing short and longer-term food security in the country (Mather et al., 2016; Pan and Christiaensen, 2012). The scaled-up program was called the NAIVS and it operated in 58 districts across 11 regions in 2008/09; the goal was to eventually reach 2.5 million households for three consecutive years each.[46] The NAIVS was initially geographically targeted to areas favorable to maize and rice production in Tanzania. However, the NAIVS program was expanded nationwide by 2011/12 due to political pressure, which allowed other rural regions to receive at least small quantities of vouchers while a substantial share of the vouchers was still concentrated in the originally designated regions (World Bank, 2014). Table 3.2 shows the number of household beneficiaries of the NAIVS program between 2008/09 and 2013/14, where the 730,667 households in the 2008/09 crop season were expected to receive vouchers for three consecutive years. The number of household beneficiaries reached its peak in 2010/11 and then

[46] The targeted regions were intially Iringa, Mbeya, Ruvuma, Rukwa, Kilimanjaro, Arusha, Manyara, Kigoma, Tabora, Mara, and Morogoro, with Pwani added in 2009/10 (World Bank, 2014).

declined as beneficiaries completed their three years of assistance. NAIVS officially ended during the 2013/14 cropping season.[47]

Table 3.2: Household beneficiaries for the NAIVS

	2008/09	2009/10	2010/11	2011/12	2012/13	2013/14
Planned	740,000	1,500,000	2,040,000	1,800,000	1,000,000	500,000
Actual	730,667	1,511,900	2,011,000	1,779,867	940,783	932,100

Source: World Bank (2014)

The major goals of NAIVS were to: (i) increase the production of maize and rice, the two major staple crops in Tanzania; (ii) improve farmers' access to inorganic fertilizer and seed for improved maize and rice varieties; and (iii) strengthen private sector improved seed and inorganic fertilizer value chains and increase agro-dealer activity at village level (World Bank, 2014; Mather et al., 2016).

Unlike Malawi's and Zambia's ISPs, which historically relied mainly on government distribution systems for subsidized inputs and have only recently started engaging the private sector in major ways, from its start, NAIVS used a much more private sector-oriented approach whereby the private sector handled importation, distribution, and retailing of the subsidized fertilizer while the government's role was limited to distributing vouchers (Mather et al., 2016).[48] In addition, NAIVS primarily targeted households with limited experience using modern inputs

[47] External funding through the World Bank was finally terminated in 2014, which was the official closure of NAIVS. However, in subsequent years the government of Tanzania continued providing input subsidies to farmers through different approaches including: (i) credit-based subsidies in 2014/15 through which the government provided loans and credit to farmer groups and cooperatives to access inputs; (ii) the government's return to using a voucher-based system in 2015/16; and (iii) subsidized fertilizer by entering into contracts with seed and fertilizer companies to supply inputs in 2016/17 (Masinjila and Lewis, 2018).

[48] In Malawi, the government parastatal distributed fertilizers from the port to parastatal depots (Mather et al., 2016) and until recently, fertilizer vouchers for the ISP could only be redeemed at government depots (and not at private agro-dealers' shops) (Lunduka et al., 2013). In Zambia, an electronic-voucher pilot program was launched in 2015/16, but until this point Zambia's program did not use vouchers; rather, subsidized fertilizers and seeds were distributed through a dedicated system that operated separately from private agro-dealers instead of through them.

but that had the farming resources required to use these inputs well (World Bank, 2014). More specifically, to be eligible for the program, beneficiaries had to: (i) have the ability and willingness to co-finance the input purchase (i.e., upon redeeming the vouchers for each subsidized input which had a face value of half of the market price, the recipient needed to pay the remaining 50% of the price); and ii) be full time farmers with one hectare or less of maize or rice under cultivation, where female-headed households and farmers that had not used modern inputs on maize or rice within the past five years were to be prioritized.[49] Given these targeting criteria, NAIVS was not intended to help the most vulnerable households among the poor because farmers who cannot co-finance the inputs purchased with the voucher are less likely to be able to purchase the inputs at market prices once subsidies are phased out. In addition, the second criterion was designed to prevent the vouchers from reaching households who were already capable of self-financing purchase of the inputs (Mather et al., 2016).

Each voucher recipient was to obtain three vouchers for three consecutive years and approximately 80% of the vouchers were assigned to maize-growing households.[50] The vouchers were for: i) one 50 kg bag of urea, ii) one 50 kg bag of Di-Ammonium Phosphates (DAP) or two 50 kg bags of Minjingu Rock Phosphate (MRP) with nitrogen supplement, and iii) 10 kg of hybrid or open-pollinated maize seed or 16 kg of rice seed, which is suitable for planting approximately one acre of land (World Bank, 2014; Pan and Christiaensen, 2012). The voucher

[49] Mather and Minde (2016) provide descriptive evidence based on data from the TNPS and a World Bank household survey that the majority of NAIVS recipients met the major targeting criteria such as voucher distribution to the most suitable regions for maize and rice production and targeted farmers who have one hectare or less of maize or rice area and who had previously not been using modern inputs within the last five years. However, out of 2.5 million voucher recipients between 2008 and 2013, only 14.7% of them were women although female-headed households were supposed to be given preference (Masinjila and Lewis, 2018).

[50] There may be lagged or enduring effects of the vouchers received for three consecutive years, but this study cannot directly control for this due to lack of data on NAIVS participation in years prior to the years captured in the surveys.

recipients were to redeem their vouchers at local agro-dealerships participating in the program and pay the 50% top-up fee for the subsidized inputs at that time.[51]

In general, the NAIVS vouchers were geographically allocated each year through a multi-stage targeting process. As the first step, a national voucher committee which consisted of central and regional government officials and representatives from private sector input supply chains would meet to determine how vouchers should be allocated among regions. Then, a similar voucher committee at the district level set the number of vouchers to assign to each district (ward/village). At each level of government, the vouchers were allocated based on the estimated numbers of farmers that could 'make best use of these inputs' instead of allocating proportionally to population size (Mather et al., 2016). At the last stage of the distribution, a village voucher committee which consisted of elected village leaders, several resident farmers, and extension agents generated a list of beneficiary farmers which was then submitted to the village assembly for approval. Finally, the input vouchers were distributed to farmers that were approved by the village assembly and met the eligibility criteria.

Among the 1,624 maize growing households in our sample (which is drawn from the 2008/09 and 2012/13 TNPSs), 6.7% (108 households) of them received vouchers for inorganic fertilizers and/or maize seed through the NAIVS program (Table 3.3). Unlike the planned input subsidy package that three vouchers be allocated to each targeted farmer, Table 3.3 shows that 65.7% of recipient households (pooled across both waves of the TNPS) obtained vouchers only for inorganic fertilizer while 11.1% of them received only a voucher for improved maize seed; just 23.1% of recipient farmers received vouchers for both inorganic fertilizer and improved

[51] Although vouchers were intended to cover 50% of the input costs, increasing fertilizer prices in some years meant that they only covered 40-45% of the input cost (World Bank, 2014).

maize seed.[52] Given the geographic targeting and eligibility criteria for NAIVS, most of these voucher recipients reside in high potential maize production regions – e.g., approximately 73.1% of them live in the Southern Highlands (i.e., Ruvuma, Iringa, Mbeya, and Rukwa regions); and 21.3% of them live in the northern part of the country (i.e., Arusha, Kilimanjaro, Tanga, Mara, and Manyara regions). Table 3.3 further shows that 87% of the sample farmers that received vouchers actually redeemed them at local agro-dealerships. According to Mather and Minde (2016), some voucher recipients did not redeem their vouchers because they could not afford the top-up fee; other recipients may have redeemed their vouchers with payment of the top-up fee and then sold one or more of their inputs to another farmer or back to the agro-dealer for cash. We cannot observe resale of inputs acquired with NAIVS vouchers in the TNPS data.

Table 3.3: Number and percentage of rural maize-growing households that received versus redeemed a NAIVS voucher by input voucher type received

	TNPS 2008/09 (%)	TNPS 2012/13 (%)	Total (%)
Voucher receipt			
Inorganic fertilizer only	14 (50.0)	57 (71.3)	71 (65.7)
Improved maize seed only	3 (10.7)	9 (11.3)	12 (11.1)
Both	11 (39.3)	14 (17.5)	25 (23.1)
Total number of households	28 (100.0)	80 (100.0)	108 (100.0)
Voucher receipt and redemption			
Inorganic fertilizer only	13 (92.9)	50 (87.7)	63 (88.7)
Improved maize seed only	2 (66.7)	8 (88.9)	10 (83.3)
Both	8 (72.7)	13 (92.9)	21 (84.0)
Total number of households	23 (82.1)	71 (88.8)	94 (87.0)

Source: Authors' calculations.

[52] In the TNPS, the reasons why farmers may not have received the full set of vouchers are not reported, but Masinjila and Lewis (2018) provide several potential explanations for this. For example, some farmers with limited financial resources may want to take a voucher for a specific input type instead of the entire package of the vouchers. In other cases, farmers were asked to sign for all the vouchers but did not receive all their inputs when inputs were delayed or local agro-dealers had run out of that input.

Table 3.4 shows the number and percentage of sample maize plots in each SI category owned by recipients of a NAIVS voucher (for inorganic fertilizer and/or improved maize seed) versus NAIVS non-recipients. Out of 2,559 maize plots, 8.4% (215 maize plots) are owned by households who received a NAIVS voucher while 91.6% (2,344 maize plots) are owned by non-recipients. Among the 215 maize plots owned by NAIVS voucher recipients, approximately 36% and 31% fall in the "Intensification" and "SI" categories, respectively. Considering the input voucher types, recipients who received a voucher for inorganic fertilizer only or vouchers for both fertilizer and maize seed are more likely to fall in the "Intensification" and "SI" groups compared to those who received improved maize seed only. On the other hand, approximately 14% and 19% of maize plots owned by NAIVS voucher recipients fall in the "Non-adoption" and "Sustainable" categories, respectively.[53] Unlike the case of the NAIVS voucher recipients, most of the maize plots owned by non-recipients fall in the "Non-adoption" and "Sustainable" categories, accounting for 48% and 39% of them, respectively. The "Intensification" and "SI" categories are much less prevalent among NAIVS non-beneficiaries, at approximately 6% and 7% of maize plots each. This may indicate that maize-producing households have difficulty affording inorganic fertilizers at unsubsidized prices.

[53] Note that even if a farmer received an inorganic fertilizer voucher, they could fall in the "Non-adoption" or "Sustainable" categories if they used the inorganic fertilizer acquired on a crop other than maize and/or if they did not redeem their voucher for inorganic fertilizer.

Table 3.4: Number and percentage of maize plots owned by NAIVS voucher recipients vs. non-recipients under SI category

	Non-adoption (row %)	Intensification (row %)	Sustainable (row %)	SI (row %)	Total (row %)
Voucher recipients	**31 (14.4)**	**77 (35.8)**	**41 (19.1)**	**66 (30.7)**	**215 (100.0)**
<u>*Input voucher type*</u>					
Inorganic fertilizer only	16 (11.2)	57 (39.9)	21 (14.7)	49 (34.3)	143 (100.0)
Improved maize seed only	10 (45.5)	1 (4.5)	9 (40.9)	2 (9.1)	22 (100.0)
Both	5 (10.0)	19 (38.0)	11 (22.0)	15 (30.0)	50 (100.0)
Non-recipients	**1,128 (48.1)**	**147 (6.3)**	**907 (38.7)**	**162 (6.9)**	**2,344 (100.0)**
Total maize plots	1,159 (45.3)	224 (8.8)	948 (37.0)	228 (8.9)	2,559 (100.0)

Source: Authors' calculations.

3.3 Methodology

3.3.1 Conceptual framework

Following previous studies (e.g., Marenya and Barrett, 2007; Di Falco and Veronesi, 2013; Teklewold et al., 2013), we use a random utility framework to conceptualize the effects of NAIVS voucher receipt on a household's use of SFM practices on a given maize plot. Let I_{imj}^{*} denote a latent variable that represents farmer i's expected utility from choosing SI category j on maize plot m, $j = 0, 1, 2, \dots, J$. ($J = 3$ in this study given that there are four SI categories). This study specifies the latent variable as:

$$I_{imjt}^{*} = \boldsymbol{X_{it}}\boldsymbol{\gamma_j} + \beta_j NAIVS_{it} + c_{ij} + \eta_{imjt}, \qquad (1)$$

where *t* indexes the agricultural year; $\boldsymbol{X_{it}}$ and $\boldsymbol{\gamma_j}$, respectively, capture the observed household, plot, and community characteristics and their corresponding parameters (discussed in Section 3.4.2 below); $NAIVS_{it}$ with associated parameter β_j is a dummy variable equal to one if the household received a NAIVS voucher for inorganic fertilizer, improved maize seed, or both, and equal to zero otherwise; c_{ij} is household-level time-invariant unobserved heterogeneity; and η_{imjt} is the time-varying error term.[54]

However, we do not directly observe the expected utility from choosing alternative j, only the choice ultimately made by the farmer. It is assumed that farmer i will choose alternative j if using j provides greater expected utility than any other alternative $h \neq j$. This can be expressed as:

$$I_{imt} = \begin{cases} 1 \; if \; I^*_{im1t} > \max_{h \neq 1}(I^*_{imht}) \\ \vdots \\ J \; if \; I^*_{imJt} > \max_{h \neq J}(I^*_{imht}) \end{cases} \qquad \text{for all h} \neq \text{j} \qquad (2)$$

3.3.2 Estimation strategy

For the empirical analysis, we apply an MNL model, which is widely used in economic applications such as studies on adoption of multiple agricultural technologies and their impacts (Grabowski et al., 2016; Teklewold et al., 2013; Kassie et al., 2015a; Khonje et al., 2018). The main advantage of using an MNL model (compared to a multivariate probit model, discussed below) is its computational simplicity in calculating choice probabilities without any requirement of multivariate integration (Tse, 1987; Hassan and Nhemachena, 2008). In addition, the log-likelihood function for the MNL specification is globally concave, which makes the maximization problem straightforward (Hausman and McFadden, 1984). The main drawback of the MNL model is the assumption of independence of irrelevant alternatives (IIA), which implies

[54] The TNPS is a household-level panel dataset, not a plot-level one; thus we are only able to control for household-level (not plot-level) time-invariant unobserved heterogeneity.

that the relative odds between any two alternatives are independent of the characteristics of the other alternatives in the choice set (Wooldridge, 2010; Hausman and McFadden, 1984).

An alternative approach to the MNL model is the multinomial probit model, which relaxes the IIA property by assuming that the residuals in a farmer's utility function (call them a_{ij} from choosing alternative j for $j = 1, 2, \dots, J$) has a multivariate normal distribution with arbitrary correlations between a_{ij} and a_{ih} for all $j \neq h$. The multinomial probit model is theoretically attractive but it also has some practical challenges: (i) the choice probabilities are very complicated, which makes it difficult to obtain partial effects on the choice probabilities; (ii) it requires that multivariate normal integrals be evaluated to estimate the unknown parameters; and (iii) it is not feasible for more than five alternatives, although this latter issue is not a constraint in the current application (Hausman and McFadden, 1984; Wooldridge, 2010). For these reasons, we use an MNL model instead of a multinomial probit model here.

Assuming that the η in equation (1) are identically and independently Gumbel distributed, the probability that farmer i characterized by $\boldsymbol{X}$, $NAIVS_{it}$, and c_{ij} in equation (1) will choose alternative j can be specified by the MNL model (McFadden, 1973) as:

$$\mathrm{P}\left(I_{imt} = j \middle| \boldsymbol{X_{it}}, NAIVS_{it}, c_{ij}\right) = \frac{\exp(\boldsymbol{X_{it}\gamma_j} + \beta_j NAIVS_{it} + c_{ij})}{\sum_{h=0}^{3} \exp(\boldsymbol{X_{it}\gamma_h} + \beta_h NAIVS_{it} + c_{ih})} \quad (3)$$

As noted above, relatively few NAIVS beneficiaries received vouchers for both inorganic fertilizer and maize seed, while approximately 66% of the recipients pooling across both waves received only vouchers for inorganic fertilizer. The effects of NAIVS voucher receipt on households' SI category decisions may differ by the type of input voucher(s) received. We therefore generate two alternative *NAIVS* variables based on input types: i) $NAIVS_{fert\_it}$ equals one if the household received a voucher for inorganic fertilizer, and ii) $NAIVS_{seed\_it}$ equals one if the household received a voucher for improved maize seed. In addition, when farmers received the vouchers but did not redeem them, the actual effects of the NAIVS program on each adoption strategy may be under- or over-estimated. We thus also estimate a set of models using another set of alternative *NAIVS* variables based on households' voucher redemption.

To control for time-constant unobserved household-level heterogeneity (c_{ij}) that may be correlated with the observed explanatory variables, a CRE/Mundlak-Chamberlain device approach is applied. This entails including the household-level time averages of the explanatory variables that change across i and t as additional regressors in equation (3) (Mundlak, 1978; Chamberlain, 1984; Wooldridge, 2010). This approach requires the assumptions of strict exogeneity of the explanatory variables conditional on the unobserved heterogeneity, and that the unobserved effects are linearly correlated with the household-level time averages of the observed explanatory variables.

Even though our model controls for time-invariant unobserved heterogeneity via CRE, we still have concerns about potential endogeneity related to time-varying unobserved heterogeneity, particularly since NAIVS beneficiaries are not randomly selected. The NAIVS voucher receipt variables (i.e., $NAIVS_{it}$, $NAIVS_{fert\_it}$, and $NAIVS_{seed\_it}$) may be systematically related to time-varying unobserved factors that influence the household's SI category decisions (η_{imjt}).

To test and control for this potential endogeneity of the *NAIVS* variables, we use the CF approach. The CF approach in the context of the current study consists of two steps (Wooldridge 2015). In the first step, we estimate a reduced form model via CRE logit in which the relevant *NAIVS* variables are the covariates in equation (3) and at least as many instrumental variables (IVs) as there are potentially endogenous *NAIVS* variables (J.M. Wooldridge, personal communication, May 2017). The logit generalized residuals obtained from the reduced form serve as the control functions. In the second step, the reduced form logit residuals are included as additional regressors in the main MNL model. If the coefficient on a given logit generalized residual variable is statistically significant at the 10% level or lower, then the null hypothesis that that *NAIVS* variable is exogenous is rejected. However, including the logit residuals in the main MNL model corrects for endogeneity of that *NAIVS* variable (Rivers and Vuong 1988). Because the logit generalized residuals are generated in a first stage estimation, we use bootstrapping to obtain valid standard errors for the parameter estimates in the MNL model (Wooldridge, 2010).

To be valid IVs, there are two requirements: i) the IVs must be strongly partially correlated with the *NAIVS* variables, and ii) partially uncorrelated with η_{imjt}, where condition ii) is a maintained assumption that cannot be tested. This study considers two candidate IVs for the *NAIVS* variables. The first IV, $Voucher_{rt}$, is the number of vouchers for inorganic fertilizer (nitrogen) distributed to region *r*. This variable is expected to be positively correlated with fertilizer and maize seed voucher receipt by a maize-growing household because most of the fertilizer vouchers are geographically targeted to the most suitable areas for maize. The second IV is $ElectoralThreat_{dt}$, which was used by Mather and Minde (2016) as an IV for the quantity of subsidized fertilizer received by a household. It is defined as the district-level (*d*) ratio of the proportion of votes for the runner-up in the most recent presidential election (Ibrahim Lipumba in 2005 and Willibrod Peter Slaa in 2010) over the proportion of votes for the winner (Jakaya Mrisho Kikwete in both 2005 and 2010).[55] According to previous studies (e.g., Banful, 2011;

[55] Both IVs, $Voucher_{rt}$ and $ElectoralThreat_{dt}$, used in this study are time-varying in addition to varying across regions and districts, respectively.To construct $ElectoralThreat_{dt}$, we used constituency-level data on electoral results from the 2005 and 2010 presidential elections and then aggregated them to the district level because the TNPS does not provide village names, which prevents us from being able to match households with their constituency. The electoral results in 2005 and 2010 were used to construct the IV for household receipt of NAIVS vouchers in TNPS 2008/09 and 2012/13, respectively.

Mason et al., 2017; Mather and Minde, 2016), past election results and voting patterns in a given area (district, constituency, etc.) have been found to affect the targeting of subsidized fertilizer in Ghana, Malawi, Zambia, and Tanzania. In Tanzania in particular, Mather and Minde (2016) found that electoral threat significantly affects the quantity of subsidized fertilizer received by the household. The reduced form CRE logit results indicate that these IVs are indeed very strongly partially correlated with the potentially endogenous *NAIVS* variables; the IVs are jointly significant for all *NAIVS* variables at the 1% level (see Table 3A.1 and Table 3A.2 in the Appendix).

Regarding requirement (ii) for the validity of the two IVs, $Voucher_{rt}$ and $ElectoralThreat_{dt}$, we argue that after controlling for the rich set of observed covariates described below and time invariant household-level unobserved heterogeneity via CRE, these variables should only affect a household's SI category decisions through their effects on the household's receipt of NAIVS vouchers. Moreover, these IVs are exogenous to an individual household because district-level election results reflect the decisions of thousands of voters and the regional allocation of NAIVS vouchers is decided by the central government.

3.4 Data and description of variables

3.4.1 Data

Our primary data source is the TNPS, which is a three-wave nationally representative household panel survey conducted in 2008/09, 2010/11, and 2012/13.[56] The TNPS was implemented by the Tanzania National Bureau of Statistics with technical assistance from the World Bank through

[56] Data from the fourth wave of the survey (TNPS 2014/15) are now publicly available. However, only 860 households corresponding to 68 clusters were selected from the TNPS 2012/13 sample as part of the 2014/15 "Extended Panel" while a new sample was entirely refreshed for all future rounds. Therefore, we consider only the first three rounds of the survey in this study.

the Living Standards Measurement Study-Integrated Surveys on Agriculture (LSMS-ISA) program. The survey captures information on agricultural production and input use, off-farm income sources, household consumption, socio-economic characteristics, and other topics. A stratified random sampling procedure was employed to select the households in four analytical strata: Dar es Salaam, other urban areas in mainland Tanzania, rural areas in mainland Tanzania, and Zanzibar. Within each stratum, clusters were randomly chosen as the primary sampling units and eight households from each cluster were randomly selected in the last stage.[57] The 2008/09 TNPS consisted of 3,265 households that were clustered in 409 enumeration areas. This original sample of 3,265 households and individual members in these households were tracked and re-interviewed in the second (2010/11 TNPS) and third rounds (2012/13 TNPS). The second round tracked 97% of the first round households and the third round tracked 96% of the second round households; thus attrition between rounds was very low (Tanzania National Bureau of Statistics, 2014).

For the empirical analysis, we exclude the second (2010/11) wave of the TNPS because the questions on NAIVS participation are not comparable to those on the first and third waves. Specifically, the survey instrument in 2010/11 recorded input voucher receipt at the plot level (only if a given input was used) and has no information on whether recipients indeed redeemed the vouchers, while the voucher receipt and redemption information in the other two rounds (2008/09 and 2012/13 TNPS) was directly collected at the household level (and so it captured all voucher receipt regardless of whether a given input was used); the latter data are used to generate the *NAIVS* variables described above. Our analytical sample involves the balanced panel of maize-growing households interviewed in both TNPS 2008/09 and 2012/13, and their associated

[57] In urban areas, the clusters are census enumeration areas based on the 2002 Population and Housing Census; in rural areas, the clusters are villages.

maize plots: 1,624 total household observations (812 observations in each round) and 2,559 total maize plots cultivated by these households (1,225 maize plots in 2008/09 and 1,334 maize plots in 2012/13).

In addition, the TNPS data provided by the World Bank include a range of secondary geospatial variables from other sources. Among these, we use in the empirical analysis the rainfall data from the National Oceanic & Atmospheric Administration-Climate Prediction Center (NOAA-CPC) and the soil nutrient availability data from the Harmonized World Soil Database.

Other data used in the analysis are: (i) monthly wholesale price data for maize and rice from the Agricultural Market Information System (AMIS) of the Ministry of Industry and Trade (MIT);[58] and (ii) constituency-level data from the 2005 and 2010 presidential elections from the national election commission of Tanzania.[59]

3.4.2 Explanatory variables

Table 3.5 provides descriptive statistics for the explanatory variables used in the analysis. These variables were selected based on a careful review of the technology adoption literature and the literature on the impacts of ISPs on SFM in other SSA countries (e.g., Pender and Gebremedhin, 2007; Ndiritu et al., 2014; Doss and Morris, 2001; de Janvry et al., 1991; Kassie et al., 2013; Kassie et al., 2015a and 2015b; Amsalu and Graaff, 2007; Morgan et al., 2019; Koppmair et al., 2017).

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[58] These prices were collected on a weekly basis from 20 wholesale markets that are matched to regions in Tanzania. Out of 26 regions in the TNPS, there are six regions that are not covered by AMIS. For the wholesale prices in these regions, we use an average price calculated from wholesale markets in adjacent regions.

[59] We thank Dr. David Mather for sharing these data.

The key explanatory variables of interest in this study are the *NAIVS* variables. Out of 1,624 household observations during TNPS 2008/09 and 2012/13, 7% of the sample (3% and 10% of the sample households in 2008/09 and 2012/13, respectively) received a NAIVS fertilizer and/or maize seed voucher ($NAIVS_{it}$). By input type of the voucher received, 6% and 2% of the sample households received a NAIVS fertilizer voucher ($NAIVS_{fert\_it}$) and a NAIVS seed voucher ($NAIVS_{seed\_it}$), respectively.

Table 3.5: Summary statistics for the variables used in the analysis

Variables	Variable description	Mean	Std. dev.
Household characteristics			
$NAIVS_{it}$	1=yes if the household received a NAIVS voucher for inorganic fertilizer and/or maize seed	0.07	0.25
$NAIVS_{fert\_it}$	1=yes if the household received a NAIVS voucher for inorganic fertilizer	0.06	0.24
$NAIVS_{seed\_it}$	1=yes if the household received a NAIVS voucher for maize seed	0.02	0.15
Male-Headed HH	1=yes if the household head is male	0.79	0.41
Age of HH head	Age of the household head (years)	48.96	15.15
Education of HH head	Highest grade completed by the household head (years)	4.74	3.38
Household endowments of physical, human, and social capital			
Family labor	Number of adults (15-64 years old) per acre of cultivated land	0.97	1.33
Total cultivated land	Total land area cultivated (acres)	6.23	10.41
Off-farm income	1 = yes if the HH earned off-income in the past 12 months	0.43	0.49
Farm assets	Total value of farm implements and machinery (1,000 TZS) owned in the past 12 months	1,131.23	5,761.07
Livestock ownership	1 = yes if the HH has livestock (cattle, goats, sheep, pigs, or donkeys)	0.46	0.50
Access to credit	1 = yes if the HH borrowed cash, goods, or services in the past 12 months	0.07	0.25
Membership (SACCOS)	1 = yes if the HH has a member of SACCOS	0.04	0.19
Agricultural extension and access to information and input suppliers			
Extension from gov't/NGO	1 = yes if the HH received agricultural advice from government/NGO in the past 12 months	0.12	0.32
Extension from cooperative	1 = yes if the HH received agricultural advice from cooperative/large scale farmer in the past 12 months	0.04	0.19
Cooperatives	1 = yes if farmers' cooperative present within the village	0.46	0.50
Input supplier	1 = yes if improved maize seed supplier present within the village	0.39	0.49
Shocks and other constraints			
Drought/Flood	1 = yes if the HH was negatively affected by drought or flood in the past two years	0.11	0.31
Crop disease/Pests	1 = yes if the HH was negatively affected by crop diseases or pests in the past two years	0.08	0.28
Rainfall	12-month total rainfall (mm) in July-June	766.64	270.51
Soil nutrient constraint	1 = yes if soil nutrient availability constraint is moderate or severe	0.62	0.49

Table 3.5 (cont'd)

Variables	Variable description	Mean	Std. dev.
Input and expected output prices			
Inorganic fertilizer price	Inorganic fertilizer price at district level (TZS/kg)	1,141.35	371.39
Real price of maize	Average price of maize from Jul. to Sep. in prior year (TZS/100kg bag)	29,941.11	7879.33
Real price of rice	Average price of rice from Jul. to Sep. in prior year (TZS/100kg bag)	91,313.88	17,695.48
Bean price	Bean market price at region level (TZS/kg)	1281.17	274.05
Groundnut price	Groundnut market price at region level (TZS/kg)	1541.44	499.50
Plot characteristics			
Plot size	Plot size (acres)	2.94	5.68
Plot tenure	1 = yes if the HH has title deed for the plot	0.09	0.28
Distance from home	Distance from plot to home (km)	3.66	20.16
Distance from main road	Distance from plot to main road (km)	2.05	5.11
Distance from market	Distance from plot to major market (km)	10.84	14.18
Good soil quality	1 = yes if farmer's perception of soil quality on the plot is good	0.50	0.50
Poor soil quality	1 = yes if farmer's perception of soil quality on the plot is poor	0.05	0.22
Flat plot slope	1 = yes if farmer's perception of the slope on the plot is flat	0.64	0.48
Moderate plot slope	1 = yes if farmer's perception of the slope on the plot is slightly sloped	0.32	0.47
Instrumental variables			
$ElectoralThreat_{d\_it}$	Proportion of votes for the presidential runner-up divided by the proportion of votes for the winner	0.24	0.47
$Voucher_{r\_it}$	Number of inorganic fertilizer (nitrogen) vouchers distributed to region	52,373.05	42,070.34

Note: The means and standard deviations for plot characteristics are calculated based on the plot level data (n=2,559), whereas the means and standard deviations for the other control variables are calculated based on the balanced household-level data (n=1,624).

This study controls for household-level heterogeneity by including characteristics of the household head – such as his/her age, gender, and education level – which are relevant variables that may influence decision-making processes within the household. That is, use of modern inputs and management practices may differ across households depending on the characteristics of the household head as a main decision-maker. For example, more educated farmers may be more aware of the benefits from the use of each SFM practice (or combined use thereof), and thus they may be more likely to purchase inputs or adopt agricultural practices that could have the potential to improve crop yields (Pender and Gebremedhin, 2007). Moreover, there may exist gender differences in adoption strategies for the SFM practices since female farmers often have less access to things like land, labor, credit, education, and information (Ndiritu et al., 2014; Doss and Morris, 2001).

In the context of imperfect or missing markets for land and labor, a household's capital endowments (physical, human, and social), represented by total cultivated land, off-farm income, farm assets, livestock ownership, family labor, access to credit, and membership in Savings and Credits Cooperatives Societies (SACCOS) in this study, may significantly affect a farmer's decision to use external inputs and SFM practices (de Janvry et al., 1991; Pender and Gebremedhin, 2007). Households with greater physical assets and social capital generally have more savings and better access to credit which would help them to finance the purchase of inputs such as inorganic fertilizer and improved seeds (Kassie et al., 2013). Livestock ownership could also facilitate use of organic fertilizer because animal manure is one of the major sources of organic fertilizer and it can rarely be purchased from the market. In addition, family labor availability, defined here as the number of adults aged 15 to 64 within the household per acre of total cultivated land, could be an important determinant of household use choices among the SFM practices. For example, particularly in the context of missing or imperfect labor markets, greater availability of family labor could enable households to choose relatively labor-intensive practices (e.g., maize-legume intercropping or organic fertilizer, or both) rather than investing in inorganic fertilizer only.

Agricultural extension services are a key channel to promote the use of modern inputs and improved management practices (Pender and Gebremedhin, 2007; Kassie et al., 2015a). We thus include two dummy variables associated with agricultural extension services depending on the organizations: i) one is a variable equal to one if the household received agricultural extension advice from government or an NGO in the past 12 months; and ii) the other equals one if the household received agricultural extension advice from a farmers' cooperative or large-scale farmer in the past 12 months. In addition, the presence of a farmers' cooperative or input supplier within the community could provide farmers with better access to information about or better physical access to farm inputs. Thus, this study includes dummy variables for the existence of a farmers' cooperative and improved maize seed supplier within the household's village as proxies for access to information and agricultural inputs.

Given that African farmers are often vulnerable to weather shocks and crop pest/disease outbreaks, which could affect their use of SFM practices in subsequent seasons, we also control for the following two binary variables (following Kassie et al., 2015b): i) drought/flood which equals one if the household was negatively affected by a drought or flood during the past two years; and ii) crop diseases/pests which equals one if the household was negatively affected by crop diseases or pests in the past two years. We also control for two geospatial variables: i) 12-month total rainfall (mm) in the household's area from July to June; and ii) soil nutrient availability constraint which equals one if soil nutrient availability in the household's area is moderate, severe, or very severe (with the base category being no or slight constraint).[60]

[60] According to the Harmonized World Soil Database, soil nutrient availability is one of the key soil qualities for crop production (where maize is used as the reference crop). It is measured based on important characteristics (i.e.,

Input and expected output prices could also be key factors when the household makes decisions to use inputs and agricultural management practices on their maize plots. In particular, there is a significant gap between the prices of leguminous crops and maize in Tanzania, and thus use of SFM practices may vary depending on the (expected) prices of these crops. (Output prices at harvest are not known at planting time.) For the price of maize, we assume naïve price expectations – i.e., that the expected harvest price of the crop equals the observed market price in the previous year. Given that the MIT collects wholesale prices throughout the year for maize, we calculate the average real wholesale price per 100 kg bag from the nearest wholesale market during the post-harvest period (i.e., from July through September) of the previous year's main season harvest; this is then included in the model as a proxy for the household's expected maize price. The data available on legume prices are more limited. Due to these data limitations, we utilize the price information available in the TNPS and include the average prices of beans and groundnuts per kilogram at region level as a proxy for the expected prices of legume crops (i.e., we assume perfect foresight). We also control for the average price of inorganic fertilizer per kilogram at district level as the major relevant input price in this study.[61]

Plot-specific attributes such as plot size, plot tenure status, distance from the plot to home/main road/market, and farmer's perception of the soil quality and slope of the plot are also included in our model. Per previous studies (Amsalu and Graaff, 2007; Kassie et al., 2013; Kassie et al., 2015a), these plot characteristics are often important determinants of the use of soil conservation and SFM practices in eastern and southern Africa including Tanzania.

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soil texture, soil organic carbon, soil pH, total exchangeable bases) of the top soil (0-30 cm) and the subsoil (30-100 cm). Moderate, severe, and very severe constraints are generally rated between 60% and 80%, between 40% and 60%, and less than 40% of the growth potential, respectively.

[61] No data are available on maize seed prices at district level.

3.5 Results

3.5.1 Test for endogeneity of household receipt of NAIVS voucher

The parameter estimates from the CRE-MNL regression models with CF approach are reported in Appendix Table 3A.3. Two sets of estimated coefficients are presented based on different *NAIVS* variables: i) *NAIVS* variable for receipt of any input voucher ($NAIVS_{it}$, column 1); and ii) two *NAIVS* variables by input types ($NAIVS_{fert\_it}$ and $NAIVS_{seed\_it}$, column 2). We find that the generalized residuals from the CF first-stage CRE logit models in both model specifications are not statistically significant, implying we fail to reject the exogeneity of the *NAIVS* variables considered in this study.[62] Similar results hold if *NAIVS* variables and residuals based on households' voucher *redemption* (instead of receipt) are used. Thus, in the remainder of this study, we focus on the results of CRE-MNL models that exclude the CF residuals. Parameter estimates for these models are reported in Table 3A.4 in the Appendix. These coefficients are the log-odds of each respective SI category ("Intensification", "Sustainable", and "SI") for each control variable relative to the reference SI category ("Non-adoption"), holding the other variables constant. To reach conclusions based on actual probabilities, we need to calculate average partial effects (APEs). We report and discuss these APEs below.

3.5.2 APEs of NAIVS voucher receipt on household use of practices in the various SI categories

Table 3.6 shows the APEs of household receipt of NAIVS vouchers on household's use of practices in various SI categories by input voucher type received (Panels A and B, column 1). As

[62] The p-values on the generalized residuals for $NAIVS_{it}$, $NAIVS_{fert\_it}$, and $NAIVS_{seed\_it}$ are 0.449, 0.498, and 0.430, respectively. Mather and Minde (2016), who used the electoral threat IV for household quantity of NAIVS fertilizer, also fail to reject exogeneity of NAIVS fertilizer quantity received.

noted in Section 3.3.2, because some farmers did not redeem their vouchers, we also report the APEs of households' voucher redemption (Panels A and B, column 2).

Table 3.6: APEs of NAIVS voucher receipt and redemption on household use of practices in the various SI categories

	NAIVS voucher receipt				NAIVS voucher redemption			
Variables	N	I	S	SI	N	I	S	SI
Panel A								
NAIVS for any input	-0.214***	0.096***	0.027	0.091***	-0.212***	0.100***	0.008	0.104***
	(0.048)	(0.015)	(0.048)	(0.016)	(0.056)	(0.016)	(0.052)	(0.015)
Panel B								
NAIVS for inorganic fertilizer	-0.251***	0.100***	0.055	0.096***	-0.219***	0.099***	0.020	0.101***
	(0.059)	(0.017)	(0.056)	(0.016)	(0.065)	(0.018)	(0.060)	(0.016)
NAIVS for maize seed	-0.034	0.011	0.023	-0.001	-0.102	0.039	0.025	0.038
	(0.074)	(0.026)	(0.074)	(0.032)	(0.097)	(0.025)	(0.089)	(0.030)

Notes: I, S, and SI denote "Intensification", "Sustainable", and "SI", respectively. *, **, and *** indicates that the corresponding coefficients are significant at the 10%, 5%, and 1% levels, respectively.

There are three main empirical findings drawn from Table 3.6. First, based on the results from Panel A in column 1, we find that receipt of a NAIVS voucher for any input (i.e., inorganic fertilizer or maize seed or both) has a significant positive effect on both the household's probability of adopting inorganic fertilizer use only ("Intensification") and joint use of inorganic fertilizer with other SFM practices ("SI") on a given maize plot. More specifically, household receipt of a NAIVS voucher is associated with a 9.6 percentage point average increase in the probability of "Intensification" on a given maize plot and a 9.1 percentage point average increase in "SI" on a given maize plot. Given high inorganic fertilizer prices and lack of liquidity and credit considered as major constraints that farmers in SSA face, this significant positive effect on household inorganic fertilizer use is entirely reasonable. This is consistent with findings in Mather and Minde (2016) that household receipt of one NAIVS fertilizer voucher (50kg of subsidized fertilizer) increases the household's probability of purchasing commercial fertilizer by 4.0 percentage points, on average. Two potential explanations of the positive effect on the "SI" group are as follows. First, for households who originally considered using inorganic fertilizer only on their maize plot, the subsidized NAIVS voucher for inorganic fertilizer and/or maize seed could free up their resources to invest in other inputs (e.g., legume seeds or organic fertilizers in our study) that facilitate joint use of these practices with inorganic fertilizer. Second, for households who initially planned use of organic fertilizer and/or maize-legume intercropping but not inorganic fertilizer, a NAIVS voucher, especially a voucher for inorganic fertilizer, could be a great incentive to or make it possible for the household to jointly use these SFM practices. The positive effect of receipt of a NAIVS voucher on the use of practices in the "SI" category on maize plots is an encouraging result, as it could suggest that NAIVS stimulated ISFM and could improve soil health of the associated maize plots as well as maize yields and yield response to inorganic fertilizer in the long term. On the other hand, we find no statistically significant effects of NAIVS voucher receipt on the use of practices in the "Sustainable" category.

The second main finding based on Table 3.6 is that the statistically significant positive effects of NAIVS on farmers' use of the practices in the "Intensification" and "SI" categories appear to be mainly driven (as expected) by receipt of a voucher for inorganic fertilizer as opposed to receipt of a voucher for maize seed. In particular, note that based on the results in Panel B, the APEs of the NAIVS inorganic fertilizer voucher are positive and statistically significant at the 1% level for the "Intensification" and "SI" categories, whereas the APE for the NAIVS maize seed voucher is not statistically different from zero. However, no significant effects of the NAIVS maize seed voucher may be explained by the very small proportion of sample households that received it. That is, there may indeed be an impact of maize seed voucher receipt, but such an impact may not be detected unless it is very large due to low statistical power.

The third main finding based on Table 3.6 is that the estimated effects of NAIVS on the use of practices in various SI categories are very similar in sign, significance, and magnitude in the results with voucher receipt (column 1) versus voucher redemption (column 2). This finding is perhaps not that surprising given that overall 87% of household beneficiaries who received at least one NAIVS voucher indeed redeemed it (Table 3.3). Nevertheless, it shows that our results are robust to alternative definitions of “participation” in NAIVS.

To further explore the above findings, we conduct additional analyses to unpack how NAIVS voucher receipt affects the use of different packages of the practices included in the “SI” group. To do this, we consider two sets of categorizations focusing on the use of at inorganic fertilizer and at least one of the Sustainable practices on a given maize plot, respectively: i) four categories based on the combinations of inorganic fertilizer and maize-legume intercropping irrespective of the use of organic fertilizer (Table 3.7), and ii) four categories based on the combinations of inorganic fertilizer and organic fertilizer irrespective of the use of maize-legume intercropping (Table 3.8). The APEs of these categorizations in CRE-MNL models are reported in Tables 3.7 and 3.8, respectively. The results suggest that household receipt of a NAIVS voucher has a positive impact on the household’s probability of using each of the inorganic fertilizer plus Sustainable practice combinations included in the “SI” group, although the effect on the probability of joint use of inorganic fertilizer and at least maize-legume intercropping is larger in magnitude. More specifically, household receipt of a NAIVS voucher for any input is associated with an 7.5 percentage point average increase in the probability of joint use of inorganic fertilizer and at least maize-legume intercropping on a given maize plot and a 2.9

percentage point average increase in the probability of joint use of inorganic fertilizer and at least organic fertilizer. Tables 3.7 and 3.8 also show that the three main findings drawn in Table 3.6 are largely upheld.[63]

Table 3.7: APEs of NAIVS voucher receipt and redemption on household sole or joint use of inorganic fertilizer and maize-legume intercropping

	NAIVS voucher receipt				NAIVS voucher redemption			
Variables	None	Inorganic fertilizer only	Maize-legume IC only	Both	None	Inorganic fertilizer only	Maize-legume IC only	Both
Panel A								
NAIVS for any input	-0.180***	0.113***	-0.009	0.075***	-0.208***	0.122***	0.001	0.084***
	(0.049)	(0.016)	(0.048)	(0.014)	(0.058)	(0.017)	(0.055)	(0.014)
Panel B								
NAIVS for inorganic fertilizer	-0.188***	0.120***	-0.007	0.075***	-0.196***	0.123***	-0.005	0.078***
	(0.060)	(0.018)	(0.057)	(0.015)	(0.066)	(0.018)	(0.063)	(0.015)
NAIVS for maize seed	-0.016	0.001	0.006	0.009	-0.065	0.036	-0.012	0.040
	(0.077)	(0.030)	(0.075)	(0.028)	(0.105)	(0.028)	(0.099)	(0.027)

Notes: *, **, and *** indicates that the corresponding coefficients are significant at the 10%, 5%, and 1% levels, respectively.

[63] In addition to these main findings, APEs of other factors influencing the use of practices in various SI categories are presented in Appendix Table 3A.5.

Table 3.8: APEs of NAIVS voucher receipt and redemption on household sole or joint use of inorganic fertilizer and organic fertilizer

	NAIVS voucher receipt				NAIVS voucher redemption			
Variables	None	Inorganic fertilizer only	Organic fertilizer only	Both	None	Inorganic fertilizer only	Organic fertilizer only	Both
Panel A								
NAIVS for any	-0.196***	0.157***	0.009	0.029***	-0.201***	0.169***	-0.002	0.034***
input	(0.035)	(0.021)	(0.028)	(0.010)	(0.039)	(0.022)	(0.030)	(0.009)
Panel B								
NAIVS for	-0.225***	0.160***	0.032	0.033***	-0.212***	0.162***	0.015	0.035***
inorganic fertilizer	(0.041)	(0.023)	(0.033)	(0.011)	(0.043)	(0.024)	(0.033)	(0.011)
NAIVS for maize	-0.014	0.018	-0.004	-0.000	-0.101	0.073*	0.012	0.015
seed	(0.063)	(0.040)	(0.042)	(0.018)	(0.105)	(0.028)	(0.099)	(0.027)

Notes: *, **, and *** indicates that the corresponding coefficients are significant at the 10%, 5%, and 1% levels, respectively.

These findings are new and important considering that previous studies (Holden and Lunduka, 2012; Koppmair et al., 2017; Morgan et al., 2019; Kassie et al., 2015a) have typically found evidence of no significant effects or negative effects of fertilizer subsidies in Malawi and Zambia on the use of SFM practices – specifically organic manure, intercropping maize with other crops, ridges, terraces and stone bunds, and fallowing – when considered individually. This may be similar with our findings of no significant effects of NAIVS voucher receipt on use of practices in the "Sustainable" group but the weight of the evidence in our study suggests significant positive subsidy program effects on inorganic fertilizer use only as well as *joint use* of inorganic fertilizer with other SFM practices – something that is not explicitly investigated in previous studies.

Although we find fairly consistent and robust evidence on the effects of Tanzania's ISP on farmers' use of SFM practices, a key limitation of the study is that although NAIVS beneficiaries were to receive input vouchers for three consecutive years, our data only capture one year of participation in the NAIVS program. Hence, our findings should be considered as the immediate or short-run effects of the NAIVS program on households' use of SFM practices rather than the long-run effects of their full participation in the program. Future research using alternative data sources (if available) could seek to address this limitation.

3.6 Conclusions and policy implications

In many African countries, government policies through large-scale ISPs have primarily focused on conventional intensification of agricultural systems involving the use of inorganic fertilizer and high-yielding crop varieties. Yet there is an emerging consensus that these conventional means are unlikely to be sufficient to sustainably intensify agricultural production. Despite heavy spending on ISPs in SSA, the productivity and welfare effects of these programs have, in many cases, been considerably smaller than expected (Jayne et al., 2018). One of the major reasons for this is low crop yield response to inorganic fertilizer on many smallholders' fields due to poor soil quality (Ibid.). Given this limited effect of ISPs, it is increasingly apparent that use of complementary SFM practices along with inorganic fertilizer is needed to improve the agronomic efficiency of inorganic fertilizer use as well as the effectiveness of ISPs (Holden, 2018; Jayne et al., 2018). However, no previous studies have investigated the effects of an African ISP on joint use of inorganic fertilizer with other SFM practices.

Using nationally representative household panel survey data from Tanzania, this study estimates the effects of household receipt of vouchers for inorganic fertilizer and/or maize seed through the NAIVS program on farmers' use of various SFM practices. Our results from CRE-MNL models suggest that receipt of a NAIVS voucher for any input (i.e., inorganic fertilizer, improved maize seed, or both) is associated with increases in maize-growing households' probability of using inorganic fertilizer only (referred to as “Intensification”) as well as joint use of inorganic fertilizer with organic fertilizer and/or maize-legume intercropping (referred to as “SI”) on a given maize plot. In addition, we find that these effects are mainly driven by receipt of a voucher for inorganic fertilizer as opposed to receipt of a voucher for improved maize seed. No statistically significant NAIVS effects are found for the practices in the “Sustainable” group (i.e., organic fertilizer use only, maize-legume intercropping use only, or both). These findings are also robust to a household’s voucher redemption status. Furthermore, we find that household receipt of a NAIVS fertilizer voucher has a positive effect on the household’s probability of adopting joint use of both combinations in the “SI” group: inorganic fertilizer with organic fertilizer and inorganic fertilizer with maize-legume intercropping, with the latter effect found to be larger in magnitude. Overall, the results suggest that Tanzania’s NAIVS program encouraged farmers’ sole use of inorganic fertilizer, but more importantly, that the program also incentivized households’ combined use of inorganic fertilizer with other complementary SFM practices, which could raise inorganic fertilizer use efficiency as well as contribute to SI goals.

The results have several policy implications, both for Tanzania and other SSA countries’ ISPs.[64] First, our main findings demonstrate that NAIVS increased households’ use of inorganic fertilizer only as well as joint use of inorganic fertilizer with organic fertilizer and/or maize-legume intercropping as sustainable forms of agricultural intensification. Although further research is needed, these positive effects could be explained by its more private sector-friendly design and more effective targeting criteria and implementation. Compared to other SSA countries’ ISPs, the NAIVS program was designed to target relatively resource poor households who have limited experience in using modern inputs and the majority of voucher recipients met

[64] Although the NAIVS program officially ended in 2014, a similar ISPs was implemented in 2015/16 and it is possible that a similar program will be re-introduced in Tanzania in the future.

these criteria (Mather and Minde, 2016).[65] In addition, our data also show that most of voucher recipients redeemed their voucher(s) at local agro-dealerships. NAIVS' positive effects on the sole use of inorganic fertilizer and joint use of it with other SFM practices may imply that developing ISPs closer to 'smart subsidy' criteria in both design and implementation is crucial to achieving the goals of ISPs and stimulating SI. In addition, because most NAIVS beneficiaries prior to NAIVS had very limited experience with using inorganic fertilizer (unlike many subsidized fertilizer recipients in Malawi and Zambia – see Ricker-Gilbert et al. (2011) and Jayne et al. (2013)) and relied mainly on organic sources of soil fertility, they may consider inorganic fertilizer to be a complement to rather than a substitute for practices like use of organic fertilizer and maize-legume intercropping. Therefore, the receipt of a NAIVS voucher for inorganic fertilizer may have encouraged households' combined use of inorganic fertilizer with these other practices. The second policy implication is related to the fact that approximately 38% of the maize plots in rural Tanzania involved maize-legume intercropping (Table 3.1) but this use rate is still far from universal and much lower relative to other countries in the region such as Kenya (Kassie et al., 2015a). Given this, promoting wider adoption of legume intercropping with maize through including a legume seed subsidy in the ISP may be a country-specific strategy to incentivize joint use of inorganic fertilizer with maize-legume intercropping as an SI strategy. However, further research is needed to identify if this policy shift would be a cost-effective means of promoting SI of maize production in Tanzania.

[65] In contrast, in Malawi and Zambia, households with greater land and asset wealth received more subsidized fertilizer through ISPs (Jayne et al., 2013). Kenya's ISPs was targeted to areas where most of rural households were already using commercially-priced inorganic fertilizer on maize a few years before the programs started (Mather and Minde, 2016).

APPENDIX

Table 3A.1: Reduced form CRE logit regression estimates of factors affecting household NAIVS voucher receipt

Variables	CRE logit (1)	CRE logit (2)	CRE logit (3)
	=1 if the household received a NAIVS voucher for inorganic fertilizer and/or maize seed	=1 if the household received a NAIVS voucher for inorganic fertilizer	=1 if the household received a NAIVS voucher for maize seed
$ElectoralThreat_{d\_it}$	0.734***	0.357	1.042***
	(0.220)	(0.632)	(0.398)
$Voucher_{r\_it}$	0.000***	0.000***	0.000***
	(0.000)	(0.000)	(0.000)
Male-Headed HH	0.422	0.380	-0.861
	(0.411)	(0.443)	(0.546)
Age of HH head	0.029	0.097**	-0.032
	(0.057)	(0.043)	(0.080)
Education of HH head	0.131**	0.160***	0.133*
	(0.052)	(0.053)	(0.074)
Family labor	0.482*	0.506*	-0.058
	(0.249)	(0.270)	(0.368)
Total cultivated land	0.382***	0.374***	0.277***
	(0.077)	(0.082)	(0.076)
Off-farm income	0.317	-0.011	1.223*
	(0.399)	(0.411)	(0.634)
Farm assets	0.000	0.000	-0.000
	(0.000)	(0.000)	(0.000)
Livestock ownership	0.977***	1.137***	0.225
	(0.354)	(0.376)	(0.495)
Access to credit	-1.514*	-1.341	-1.596
	(0.831)	(0.895)	(1.056)
Extension from gov't/NGO	0.472	0.153	-0.317
	(0.519)	(0.531)	(0.737)
Extension from cooperative	0.349	0.218	0.302
	(0.751)	(0.806)	(1.107)
Cooperative	0.102	0.178	-1.257**
	(0.335)	(0.362)	(0.623)
Input supplier	0.890***	1.031***	1.636***
	(0.323)	(0.344)	(0.557)
Drought/Flood	-1.262*	-1.073	-1.223
	(0.665)	(0.793)	(0.951)
Crop disease/Pests	0.299	0.705	-0.508
	(0.802)	(0.974)	(1.330)
Rainfall	-0.003*	-0.004*	-0.001
	(0.002)	(0.002)	(0.003)
Soil nutrient constraint	3.973***	3.581**	1.881
	(1.508)	(1.762)	(1.381)

Table 3A.1 (cont'd)

Variables	CRE logit (1) =1 if the household received a NAIVS voucher for inorganic fertilizer and/or maize seed	CRE logit (2) =1 if the household received a NAIVS voucher for inorganic fertilizer	CRE logit (3) =1 if the household received a NAIVS voucher for maize seed
Inorganic fertilizer price	-0.001*	-0.002*	-0.001
	(0.001)	(0.001)	(0.001)
Real price of maize	0.000**	0.000*	-0.000
	(0.000)	(0.000)	(0.000)
Real price of rice	-0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)
Bean price	0.001	0.001	0.002
	(0.001)	(0.001)	(0.004)
Groundnut price	0.001	0.001	0.002
	(0.001)	(0.001)	(0.003)
Plot size	-0.045	-0.036	-0.053
	(0.031)	(0.034)	(0.035)
Plot tenure	-0.209	-0.147	-1.370**
	(0.412)	(0.443)	(0.638)
Distance from home	0.009*	0.012**	-0.005***
	(0.005)	(0.005)	(0.002)
Distance from main road	-0.076	-0.072	-0.269
	(0.059)	(0.060)	(0.165)
Distance from market	-0.005	-0.010	0.011
	(0.009)	(0.010)	(0.011)
Good soil quality	0.215	0.328	-0.034
	(0.236)	(0.251)	(0.302)
Poor soil quality	0.025	0.235	-0.861
	(0.463)	(0.430)	(0.939)
Flat plot slope	0.120	-0.010	-0.483
	(0.432)	(0.444)	(0.599)
Moderate plot slope	0.046	-0.011	-0.743
	(0.440)	(0.456)	(0.676)
Constant	-21.132***	-17.583***	-32.942***
	(4.230)	(4.016)	(9.691)
Joint significance of IVs	41.52***	43.72***	16.20***
Pseudo R-squared	0.426	0.445	0.442
Observations	2,599	2,599	2,599

Notes: *, **, and *** indicates that the corresponding coefficients are significant at the 10%, 5%, and 1% levels, respectively. Time-averages of household characteristics to control for time invariant unobserved heterogeneity were included in the model but not reported in Table 3A.1. Robust standard errors clustered at the household level are in parentheses.

Table 3A.2: Reduced form CRE logit regression estimates of factors affecting household NAIVS voucher redemption

	CRE logit (1)	CRE logit (2)	CRE logit (3)
Variables	=1 if the household redeemed a NAIVS voucher for inorganic fertilizer and/or maize seed	=1 if the household redeemed a NAIVS voucher for inorganic fertilizer	=1 if the household redeemed a NAIVS voucher for maize seed
$ElectoralThreat_{d\_it}$	0.778***	0.210	1.125**
	(0.220)	(0.747)	(0.441)
$Voucher_{r\_it}$	0.000***	0.000***	0.000***
	(0.000)	(0.000)	(0.000)
Male-Headed HH	0.572	0.600	-0.529
	(0.421)	(0.463)	(0.613)
Age of HH head	0.039	0.121***	0.018
	(0.063)	(0.040)	(0.077)
Education of HH head	0.133***	0.154***	0.162**
	(0.049)	(0.051)	(0.074)
Family labor	0.459**	0.477**	0.019
	(0.209)	(0.214)	(0.294)
Total cultivated land	0.336***	0.345***	0.191**
	(0.072)	(0.078)	(0.087)
Off-farm income	0.286	0.196	1.285*
	(0.409)	(0.435)	(0.718)
Farm assets	0.000	0.000	-0.000*
	(0.000)	(0.000)	(0.000)
Livestock ownership	1.144***	1.215***	0.398
	(0.389)	(0.414)	(0.611)
Access to credit	-1.987*	-1.916	-3.331***
	(1.076)	(1.254)	(1.287)
Extension from gov't/NGO	0.167	0.043	-1.003
	(0.552)	(0.572)	(0.741)
Extension from cooperative	0.363	0.265	0.814
	(0.751)	(0.824)	(0.939)
Cooperative	0.247	0.277	-0.809
	(0.340)	(0.371)	(0.688)
Input supplier	0.899***	1.048***	1.518***
	(0.328)	(0.358)	(0.580)
Drought/Flood	-0.474	-0.601	0.424
	(0.638)	(0.785)	(0.881)
Crop disease/Pests	0.593	1.148	0.149
	(0.826)	(1.040)	(1.311)
Rainfall	-0.003	-0.003	0.002
	(0.002)	(0.002)	(0.004)
Soil nutrient constraint	3.693**	3.626*	3.396*
	(1.575)	(1.964)	(1.760)

Table 3A.2 (cont'd)

Variables	CRE logit (1) =1 if the household redeemed a NAIVS voucher for inorganic fertilizer and/or maize seed	CRE logit (2) =1 if the household redeemed a NAIVS voucher for inorganic fertilizer	CRE logit (3) =1 if the household redeemed a NAIVS voucher for maize seed
Inorganic fertilizer price	-0.001	-0.002	-0.001
	(0.001)	(0.001)	(0.002)
Real price of maize	0.000**	0.000*	0.000
	(0.000)	(0.000)	(0.000)
Real price of rice	-0.000	0.000	-0.000
	(0.000)	(0.000)	(0.000)
Bean price	0.001	0.001	0.004
	(0.002)	(0.002)	(0.005)
Groundnut price	0.001	0.000	0.003
	(0.001)	(0.001)	(0.004)
Plot size	-0.030	-0.031	-0.022
	(0.029)	(0.033)	(0.035)
Plot tenure	-0.295	-0.113	-2.482**
	(0.461)	(0.461)	(1.045)
Distance from home	0.010**	0.014***	-0.003
	(0.005)	(0.005)	(0.003)
Distance from main road	-0.124**	-0.136**	-0.176
	(0.060)	(0.061)	(0.150)
Distance from market	-0.013	-0.012	-0.020
	(0.012)	(0.012)	(0.014)
Good soil quality	0.033	0.162	-0.430
	(0.255)	(0.273)	(0.355)
Poor soil quality	0.136	0.338	-0.265
	(0.433)	(0.419)	(0.897)
Flat plot slope	0.334	0.239	-0.087
	(0.469)	(0.462)	(0.663)
Moderate plot slope	0.251	0.211	-0.628
	(0.487)	(0.491)	(0.698)
Constant	-21.672***	-18.865***	-35.252***
	(4.836)	(4.623)	(12.584)
Joint significance of IVs	38.74***	36.46***	10.19***
Pseudo R-squared	0.436	0.462	0.484
Observations	2,559	2,559	2,559

Notes: *, **, and *** indicates that the corresponding coefficients are significant at the 10%, 5%, and 1% levels, respectively. Time-averages of household characteristics to control for time invariant unobserved heterogeneity were included in the model but not reported in Table 3A.2. Robust standard errors clustered at the household level are in parentheses.

Table 3A.3: CRE-MNL with CF regression results (relative log odds)

	CRE-MNL with CF (1)			CRE-MNL with CF (2)		
Variables	I	S	SI	I	S	SI
Male-Headed HH	-0.208	-0.039	-0.480	-0.167	-0.040	-0.432
	(0.270)	(0.149)	(0.339)	(0.267)	(0.150)	(0.342)
Age of HH head	-0.028	-0.001	-0.014	-0.034	-0.003	-0.025
	(0.033)	(0.016)	(0.025)	(0.034)	(0.016)	(0.024)
Education of HH head	0.141***	0.019	0.112**	0.141***	0.017	0.109**
	(0.048)	(0.018)	(0.049)	(0.047)	(0.018)	(0.047)
Family labor	-0.163	0.117**	-0.011	-0.146	0.110**	-0.013
	(0.149)	(0.051)	(0.178)	(0.131)	(0.051)	(0.179)
Total cultivated land	-0.104**	-0.035**	-0.112*	-0.099**	-0.035**	-0.110*
	(0.048)	(0.017)	(0.060)	(0.049)	(0.017)	(0.059)
Off-farm income	-0.100	0.111	-0.533*	-0.086	0.133	-0.495
	(0.321)	(0.167)	(0.317)	(0.327)	(0.170)	(0.303)
Farm assets	-0.000	-0.000	0.000	-0.000	-0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Livestock ownership	0.333	0.355***	0.802***	0.360	0.345***	0.791***
	(0.274)	(0.125)	(0.300)	(0.283)	(0.126)	(0.295)
Access to credit	0.670	0.042	1.130**	0.670	0.038	1.096**
	(0.457)	(0.214)	(0.452)	(0.435)	(0.209)	(0.445)
Extension from	0.585	-0.059	0.517	0.664	-0.054	0.574
gov't/NGO	(0.411)	(0.186)	(0.399)	(0.425)	(0.187)	(0.392)
Extension from	0.380	0.408	0.943**	0.422	0.432	0.994**
cooperative	(0.624)	(0.499)	(0.435)	(0.633)	(0.511)	(0.462)
Cooperative	0.408	0.038	0.200	0.432	0.030	0.208
	(0.420)	(0.149)	(0.403)	(0.427)	(0.146)	(0.405)
Input supplier	0.147	-0.042	0.300	0.136	-0.053	0.269
	(0.347)	(0.130)	(0.354)	(0.352)	(0.132)	(0.359)
Drought/Flood	0.762	-0.221	0.568	0.843	-0.238	0.540
	(0.682)	(0.210)	(0.443)	(0.731)	(0.213)	(0.463)
Crop disease/Pests	0.248	-0.071	0.167	0.237	-0.101	0.118
	(0.584)	(0.266)	(0.756)	(0.586)	(0.266)	(0.766)
Rainfall	-0.001	0.000	-0.001	-0.001	0.000	-0.001
	(0.002)	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)
Soil nutrient constraint	-0.925	-2.236**	-1.843	-0.937	-2.222**	-1.792
	(1.547)	(1.078)	(1.297)	(1.597)	(1.090)	(1.320)
Inorganic fertilizer price	0.002***	0.000	0.001*	0.002***	0.000	0.001*
	(0.001)	(0.000)	(0.001)	(0.001)	(0.000)	(0.001)
Real price of maize	-0.000	-0.000**	-0.000	-0.000	-0.000**	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Real price of rice	0.000	-0.000	0.000	0.000	-0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Bean price	-0.000	-0.001	-0.001	0.000	-0.001	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.001)
Groundnut price	-0.000	0.001**	0.000	-0.001	0.001**	0.000
	(0.001)	(0.000)	(0.001)	(0.001)	(0.000)	(0.001)

Table 3A.3 (cont'd)

	CRE-MNL with CF (1)			CRE-MNL with CF (2)		
Variables	I	S	SI	I	S	SI
Plot size	0.095**	0.043**	0.125**	0.095**	0.043**	0.124**
	(0.046)	(0.018)	(0.054)	(0.046)	(0.018)	(0.054)
Plot tenure	-0.067	0.188	0.524	-0.037	0.183	0.542
	(0.579)	(0.211)	(0.495)	(0.591)	(0.209)	(0.509)
Distance from home	-0.016	-0.046***	-0.007	-0.016	-0.047***	-0.007
	(0.012)	(0.015)	(0.016)	(0.012)	(0.015)	(0.015)
Distance from main road	-0.041	0.021	-0.048	-0.038	0.022	-0.048
	(0.035)	(0.018)	(0.044)	(0.035)	(0.018)	(0.044)
Distance from market	0.001	0.004	-0.010	-0.000	0.005	-0.010
	(0.010)	(0.005)	(0.011)	(0.010)	(0.006)	(0.011)
Good soil quality	0.048	-0.241**	-0.323	0.037	-0.242**	-0.346
	(0.228)	(0.120)	(0.216)	(0.233)	(0.121)	(0.214)
Poor soil quality	-0.685	-0.167	0.252	-0.678	-0.180	0.216
	(2.737)	(0.241)	(0.464)	(2.644)	(0.242)	(0.471)
Flat plot slope	1.797	0.065	0.189	1.844	0.074	0.241
	(4.815)	(0.310)	(0.688)	(4.816)	(0.311)	(0.676)
Moderate plot slope	1.714	0.241	0.286	1.755	0.246	0.341
	(4.727)	(0.313)	(0.623)	(4.728)	(0.314)	(0.617)
NAIVS for any input	2.912**	0.846	3.056***			
($NAIVS_{it}$)	(1.316)	(0.729)	(1.183)			
CRE logit residuals	-0.581	-0.324	-0.883			
(Any input)	(1.343)	(0.777)	(1.166)			
NAIVS for inorganic				2.595*	1.394	3.147***
fertilizer ($NAIVS_{fert\_it}$)				(1.405)	(0.860)	(1.165)
NAIVS for maize seed				2.103	-0.162	1.328
($NAIVS_{seed\_it}$)				(1.654)	(1.113)	(1.632)
CRE logit residuals				0.004	-0.760	-0.778
(Inorganic fertilizer)				(1.395)	(1.014)	(1.148)
CRE logit residuals				-2.248	0.351	-1.440
(Improved maize seed)				(1.747)	(1.116)	(1.826)

Notes: Bootstrapped standard are in parentheses. To control for time-invariant unobserved household heterogeneity, time-averages of household characteristics were included in the model but not reported in Table 3A.3. I, S, and SI denote "Intensification", "Sustainable", and "SI", respectively, where base category is "Non-adoption". *, **, and *** indicates that the corresponding coefficients are significant at the 10%, 5%, and 1% levels, respectively.

Table 3A.4: CRE-MNL without CF regression results (relative log odds)

	Voucher receipt (1)			Voucher receipt (2)			Voucher redemption (1)			Voucher redemption (2)		
Variables	I	S	SI	I	S	SI	I	S	SI	I	S	SI
Male-Headed HH	-0.164	0.048	-0.407	-0.158	0.051	-0.399	-0.191	0.047	-0.444	-0.190	0.044	-0.435
	(0.335)	(0.143)	(0.300)	(0.338)	(0.143)	(0.302)	(0.336)	(0.143)	(0.297)	(0.338)	(0.143)	(0.299)
Age of HH head	-0.037	0.004	-0.017	-0.048*	0.003	-0.027	-0.037	0.003	-0.018	-0.047	0.004	-0.028
	(0.032)	(0.015)	(0.030)	(0.029)	(0.015)	(0.027)	(0.033)	(0.015)	(0.031)	(0.031)	(0.015)	(0.028)
Education of HH head	0.126***	0.002	0.099**	0.121***	0.001	0.098**	0.129***	0.002	0.103**	0.124***	0.001	0.102**
	(0.040)	(0.019)	(0.041)	(0.040)	(0.019)	(0.041)	(0.039)	(0.019)	(0.040)	(0.040)	(0.019)	(0.040)
Family labor	-0.123	0.147***	0.024	-0.134	0.146***	0.017	-0.138	0.146***	0.000	-0.145	0.146***	-0.000
	(0.146)	(0.055)	(0.131)	(0.146)	(0.055)	(0.132)	(0.150)	(0.054)	(0.134)	(0.149)	(0.055)	(0.133)
Total cultivated land	-0.101**	-0.028*	-0.124***	-0.098**	-0.028*	-0.121***	-0.104***	-0.027*	-0.130***	-0.107***	-0.027*	-0.131***
	(0.040)	(0.015)	(0.045)	(0.040)	(0.015)	(0.045)	(0.040)	(0.014)	(0.045)	(0.041)	(0.014)	(0.044)
Off-farm income	-0.071	0.100	-0.466*	-0.029	0.112	-0.428	-0.099	0.105	-0.493*	-0.074	0.107	-0.465*
	(0.291)	(0.143)	(0.263)	(0.294)	(0.142)	(0.261)	(0.291)	(0.142)	(0.265)	(0.291)	(0.142)	(0.262)
Farm assets	-0.000	-0.000*	0.000	-0.000	-0.000*	0.000	-0.000	-0.000*	0.000	-0.000	-0.000*	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Livestock ownership	0.429*	0.462***	0.925***	0.423*	0.461***	0.927***	0.432*	0.462***	0.910***	0.430*	0.463***	0.908***
	(0.255)	(0.123)	(0.234)	(0.254)	(0.123)	(0.233)	(0.252)	(0.123)	(0.233)	(0.249)	(0.123)	(0.232)
Access to credit	0.740*	0.007	1.142***	0.713*	0.004	1.097***	0.761*	-0.003	1.203***	0.783**	-0.001	1.201***
	(0.411)	(0.234)	(0.423)	(0.413)	(0.234)	(0.421)	(0.398)	(0.233)	(0.392)	(0.395)	(0.233)	(0.390)
Extension from	0.657*	-0.091	0.653*	0.697**	-0.084	0.679**	0.695**	-0.070	0.673**	0.749**	-0.073	0.719**
gov’t/NGO	(0.336)	(0.196)	(0.337)	(0.342)	(0.197)	(0.343)	(0.334)	(0.194)	(0.337)	(0.335)	(0.194)	(0.342)
Extension from	0.508	0.561	0.999**	0.551	0.572	1.040**	0.515	0.561	1.009**	0.539	0.559	1.042**
cooperative	(0.534)	(0.422)	(0.417)	(0.546)	(0.425)	(0.419)	(0.546)	(0.422)	(0.425)	(0.555)	(0.423)	(0.436)
Cooperative	0.467*	0.144	0.324	0.465*	0.144	0.315	0.467*	0.142	0.331	0.465*	0.143	0.331
	(0.253)	(0.114)	(0.216)	(0.251)	(0.115)	(0.218)	(0.254)	(0.114)	(0.219)	(0.249)	(0.114)	(0.220)
Input supplier	0.189	-0.051	0.336	0.163	-0.057	0.321	0.190	-0.046	0.321	0.156	-0.048	0.300
	(0.223)	(0.107)	(0.226)	(0.227)	(0.107)	(0.226)	(0.223)	(0.107)	(0.225)	(0.227)	(0.107)	(0.226)
Drought/Flood	0.643	-0.234	0.473	0.628	-0.239	0.439	0.543	-0.260	0.396	0.526	-0.261	0.360
	(0.458)	(0.207)	(0.413)	(0.466)	(0.208)	(0.418)	(0.450)	(0.205)	(0.396)	(0.455)	(0.205)	(0.396)
Crop disease/Pests	0.204	-0.166	0.235	0.105	-0.180	0.163	0.165	-0.161	0.177	0.058	-0.167	0.076
	(0.510)	(0.261)	(0.511)	(0.502)	(0.261)	(0.504)	(0.509)	(0.261)	(0.515)	(0.505)	(0.261)	(0.504)
Rainfall	-0.001	0.000	-0.001	-0.001	0.000	-0.001	-0.001	0.000	-0.001	-0.001	0.000	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)

Table 3A.4 (cont'd)

	Voucher receipt (1)			Voucher receipt (2)			Voucher redemption (1)			Voucher redemption (2)		
Variables	I	S	SI	I	S	SI	I	S	SI	I	S	SI
Soil nutrient constraint	-1.081	-2.258***	-1.733**	-1.095	-2.256***	-1.729**	-1.096	-2.264***	-1.734**	-1.080	-2.266***	-1.713**
	(0.926)	(0.708)	(0.791)	(0.918)	(0.711)	(0.788)	(0.928)	(0.707)	(0.786)	(0.918)	(0.708)	(0.782)
Inorganic fertilizer price	0.002***	0.000	0.001**	0.002***	0.000	0.001**	0.002***	0.000	0.001**	0.002***	0.000	0.001**
	(0.001)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)
Real price of maize	-0.000	-0.000**	-0.000	-0.000	-0.000**	-0.000	-0.000	-0.000**	-0.000	-0.000	-0.000**	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Real price of rice	0.000**	-0.000	0.000	0.000**	-0.000	0.000	0.000**	-0.000	0.000	0.000**	-0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Bean price	-0.000	-0.000	-0.001	-0.000	-0.000	-0.001	-0.000	-0.000	-0.001	-0.000	-0.000	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Groundnut price	-0.000	0.001**	0.000	-0.000	0.001**	0.000	-0.000	0.001**	0.000	-0.000	0.001**	0.000
	(0.001)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)
Plot size	0.101***	0.036**	0.139***	0.100***	0.037**	0.137***	0.104***	0.036**	0.143***	0.107***	0.036**	0.145***
	(0.034)	(0.016)	(0.038)	(0.034)	(0.016)	(0.038)	(0.034)	(0.015)	(0.038)	(0.034)	(0.015)	(0.038)
Plot tenure	0.047	0.237	0.468	0.038	0.241	0.442	0.087	0.244	0.494	0.097	0.246	0.494
	(0.400)	(0.188)	(0.393)	(0.396)	(0.188)	(0.393)	(0.403)	(0.188)	(0.400)	(0.396)	(0.188)	(0.400)
Distance from home	-0.014*	-0.053***	-0.007**	-0.015*	-0.053***	-0.007**	-0.015*	-0.052***	-0.007***	-0.016*	-0.052***	-0.007***
	(0.007)	(0.014)	(0.003)	(0.008)	(0.014)	(0.003)	(0.008)	(0.014)	(0.003)	(0.009)	(0.014)	(0.003)
Distance from main road	-0.029	0.023	-0.042	-0.027	0.023	-0.041	-0.022	0.023	-0.038	-0.019	0.023	-0.035
	(0.031)	(0.015)	(0.035)	(0.031)	(0.015)	(0.035)	(0.031)	(0.015)	(0.036)	(0.031)	(0.015)	(0.035)
Distance from market	-0.004	0.002	-0.012	-0.004	0.002	-0.011	-0.004	0.002	-0.011	-0.004	0.002	-0.011
	(0.006)	(0.005)	(0.008)	(0.006)	(0.005)	(0.008)	(0.006)	(0.005)	(0.008)	(0.006)	(0.005)	(0.008)
Good soil quality	0.022	-0.248**	-0.271	0.007	-0.249**	-0.287	0.056	-0.242**	-0.248	0.046	-0.242**	-0.260
	(0.214)	(0.109)	(0.211)	(0.214)	(0.109)	(0.211)	(0.214)	(0.109)	(0.210)	(0.214)	(0.109)	(0.211)
Poor soil quality	-0.556	-0.155	0.398	-0.583	-0.162	0.357	-0.576	-0.159	0.367	-0.597	-0.162	0.322
	(0.518)	(0.249)	(0.405)	(0.520)	(0.249)	(0.409)	(0.518)	(0.249)	(0.411)	(0.523)	(0.249)	(0.414)
Flat plot slope	1.653**	0.011	0.150	1.674**	0.016	0.179	1.587**	0.012	0.078	1.598**	0.013	0.115
	(0.813)	(0.257)	(0.502)	(0.819)	(0.258)	(0.498)	(0.794)	(0.257)	(0.478)	(0.793)	(0.257)	(0.470)
Moderate plot slope	1.486*	0.160	0.117	1.512*	0.162	0.151	1.413*	0.161	0.038	1.439*	0.163	0.086
	(0.795)	(0.260)	(0.513)	(0.800)	(0.261)	(0.509)	(0.771)	(0.260)	(0.488)	(0.771)	(0.261)	(0.481)

Table 3A.4 (cont'd)

Variables	Voucher receipt (1)			Voucher receipt (2)			Voucher redemption (1)			Voucher redemption (2)		
	I	S	SI	I	S	SI	I	S	SI	I	S	SI
NAIVS for any input	2.382***	0.610**	2.229***				2.507***	0.552*	2.449***			
($NAIVS_{it}$)	(0.323)	(0.249)	(0.321)				(0.356)	(0.284)	(0.335)			
NAIVS for inorganic				2.580***	0.786***	2.426***				2.510***	0.603*	2.430***
fertilizer ($NAIVS_{it\_fert}$)				(0.376)	(0.301)	(0.350)				(0.398)	(0.325)	(0.363)
NAIVS for maize seed				0.267	0.148	0.108				1.028*	0.324	0.979
($NAIVS_{it\_seed}$)				(0.535)	(0.372)	(0.578)				(0.551)	(0.478)	(0.603)

Notes: Robust standard are in parentheses. To control for time-invariant unobserved household heterogeneity, time-averages of household characteristics were included in the model but not reported in Table 3A.4. I, S, and SI denote "Intensification", "Sustainable", and "SI", respectively, where base category is "Non-adoption". *, **, and *** indicates that the corresponding coefficients are significant at the 10%, 5%, and 1% levels, respectively.

Table 3A.5: APEs of other (non-NAIVS-related) factors affecting household use of practices in the various SI categories

	CRE-MNL with voucher receipt			CRE-MNL with voucher redemption		
Variables	I	S	SI	I	S	SI
Male-Headed HH	-0.004	0.023	-0.025	-0.005	0.024	-0.027
	(0.019)	(0.029)	(0.017)	(0.019)	(0.029)	(0.017)
Age of HH head	-0.002	0.002	-0.001	-0.002	0.002	-0.001
	(0.002)	(0.003)	(0.002)	(0.002)	(0.003)	(0.002)
Education of HH head	0.006***	-0.004	0.004*	0.006***	-0.005	0.004*
	(0.002)	(0.004)	(0.002)	(0.002)	(0.004)	(0.002)
Family labor	-0.011	0.033***	0.000	-0.011	0.034***	-0.001
	(0.008)	(0.011)	(0.007)	(0.008)	(0.011)	(0.007)
Total cultivated land	-0.003	-0.001	-0.006**	-0.004	-0.001	-0.006**
	(0.002)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Off-farm income	0.002	0.034	-0.032**	0.000	0.036	-0.033**
	(0.016)	(0.029)	(0.015)	(0.016)	(0.028)	(0.015)
Farm assets	-0.000	-0.000*	0.000	-0.000	-0.000*	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Livestock ownership	0.001	0.066***	0.042***	0.002	0.067***	0.041***
	(0.014)	(0.025)	(0.013)	(0.014)	(0.025)	(0.013)
Access to credit	0.026	-0.041	0.062***	0.026	-0.045	0.066***
	(0.021)	(0.047)	(0.024)	(0.021)	(0.046)	(0.022)
Extension from	0.031	-0.048	0.034*	0.032*	-0.045	0.034*
gov't/NGO	(0.019)	(0.040)	(0.021)	(0.019)	(0.039)	(0.021)
Extension from	0.003	0.084	0.043*	0.003	0.084	0.044*
cooperative	(0.028)	(0.080)	(0.023)	(0.028)	(0.080)	(0.022)
Cooperative	0.020	0.013	0.010	0.020	0.013	0.010
	(0.014)	(0.023)	(0.013)	(0.014)	(0.023)	(0.013)
Input supplier	0.007	-0.023	0.020	0.007	-0.021	0.019
	(0.012)	(0.022)	(0.014)	(0.012)	(0.021)	(0.014)
Drought/Flood	0.036	-0.074*	0.026	0.032	-0.075*	0.023
	(0.026)	(0.042)	(0.025)	(0.026)	(0.042)	(0.024)
Crop disease/Pests	0.012	-0.045	0.016	0.010	-0.041	0.013
	(0.029)	(0.052)	(0.030)	(0.028)	(0.052)	(0.030)
Rainfall	-0.000	0.000	-0.000	-0.000	0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Soil nutrient constraint	0.008	-0.413***	-0.041	0.007	-0.414***	-0.040
	(0.042)	(0.127)	(0.031)	(0.043)	(0.127)	(0.031)
Inorganic fertilizer price	0.000***	-0.000	0.000	0.000***	-0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Real price of maize	-0.000	-0.000*	-0.000	-0.000	-0.000*	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Real price of rice	0.000**	-0.000	0.000	0.000**	-0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Bean price	0.000	-0.000	-0.000	0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Groundnut price	-0.000	0.000**	0.000	-0.000	0.000**	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

Table 3A.5 (cont'd)

Variables	CRE-MNL with voucher receipt			CRE-MNL with voucher redemption		
	I	S	SI	I	S	SI
Plot size	0.003*	0.002	0.007***	0.003*	0.002	0.007***
	(0.002)	(0.003)	(0.002)	(0.002)	(0.003)	(0.002)
Plot tenure	-0.010	0.038	0.024	-0.008	0.038	0.025
	(0.021)	(0.038)	(0.022)	(0.021)	(0.038)	(0.022)
Distance from home	0.000	-0.011***	0.001**	0.000	-0.011***	0.001**
	(0.001)	(0.003)	(0.000)	(0.001)	(0.003)	(0.000)
Distance from main road	-0.002	0.006**	-0.003	-0.001	0.006*	-0.003
	(0.002)	(0.003)	(0.002)	(0.002)	(0.003)	(0.002)
Distance from market	-0.000	0.001	-0.001	-0.000	0.001	-0.001
	(0.000)	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)
Good soil quality	0.011	-0.046**	-0.012	0.012	-0.046**	-0.011
	(0.012)	(0.022)	(0.012)	(0.012)	(0.022)	(0.012)
Poor soil quality	-0.038	-0.031	0.039	-0.038	-0.031	0.038
	(0.029)	(0.049)	(0.024)	(0.029)	(0.049)	(0.025)
Flat plot slope	0.098**	-0.034	-0.018	0.095**	-0.031	-0.022
	(0.048)	(0.056)	(0.031)	(0.047)	(0.055)	(0.030)
Moderate plot slope	0.086*	0.001	-0.021	0.083*	0.005	-0.026
	(0.047)	(0.055)	(0.032)	(0.045)	(0.055)	(0.031)

Notes: To control for time-invariant unobserved household heterogeneity, time-averages of household characteristics were included in the model but not reported in Table 3A.5. I, S, and SI denote "Intensification", "Sustainable", and "SI", respectively. *, **, and *** indicates that the corresponding coefficients are significant at the 10%, 5%, and 1% levels, respectively.

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