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The Impacts of Sustainable Intensification of Maize Production on Household Crop Income, Productivity, and Food Access in Rural Tanzania

By

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ABSTRACT

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 this context, researchers and policymakers are increasingly interested in how to achieve sustainable agricultural intensification (SI) and to leverage it to meet food security and environmental objectives. Yet, there is little empirical evidence of the impacts of SI on smallholder farm household welfare and food security. Using nationally representative household panel survey data from Tanzania, this study investigates 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. These practices are the use of inorganic fertilizer, organic fertilizer (manure or compost), and maize-legume intercropping. The eight possible combinations of the use of these three focal SFM practices on households' maize plots are grouped into four SI categories: "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" (use of inorganic fertilizer jointly with at least one of the practices in the "Sustainable" category). 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 (per acre and per adult equivalent) 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 (a modified household dietary diversity score, food consumption score and food expenditure per adult equivalent); the size of these "SI" effects is similar to or greater than those of "Sustainable" practices and consistently larger than the effects of "Intensification".

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ACRONYMS AND ABBREVIATIONS

AMIS	Agricultural Market Information System
ATT	Average treatment effects on the treated
ATU	Average treatment effects on the untreated
CA	Conservation Agriculture
CRE	Correlated random effects
FCS	Food consumption score
HDDS	Household dietary diversity score
IMR	Inverse Mills ratio
ISFM	Integrated Soil Fertility Management
IV	Instrumental variable
LSMS-ISA	Living Standards Measurement Study-Integrated Surveys on Agriculture
MESR	Multinomial endogenous switching regression
MIT	Ministry of Industry and Trade
MNLS	Multinomial logit selection
NAIVS	National Agricultural Input Voucher Scheme
OLS	Ordinary least squares
SACCOS	Savings and Credits Cooperatives Societies
SFM	Soil fertility management
SOM	Soil organic matter
SSA	Sub-Saharan Africa
TNBS	Tanzania National Bureau of Statistics
TNPS	Tanzania National Panel Surveys
TZS	Tanzania Shillings

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.[1] 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 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.[2]

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

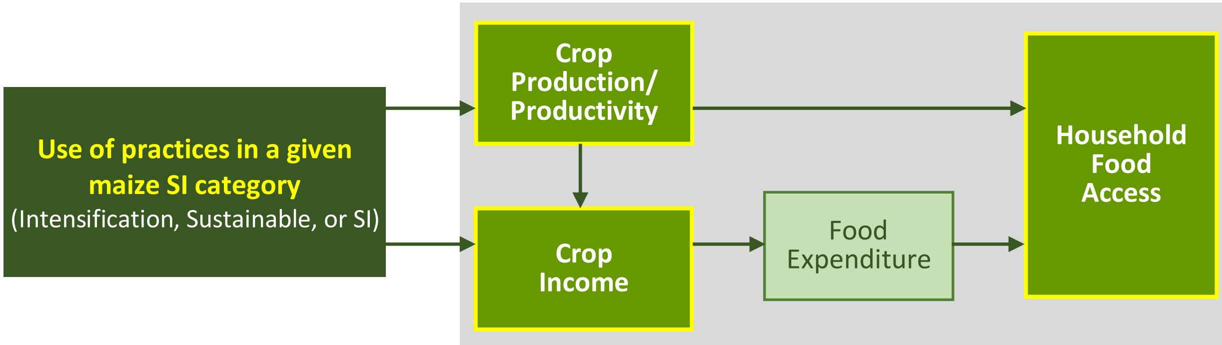
[1] Food security is defined as when "all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (FAO 1996). Food security consists of four dimensions: food availability, access, utilization, and stability.
[2] 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.

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.[3] The three focal SFM practices are inorganic fertilizer, organic fertilizer, and maize-legume intercropping.[4] 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 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).[5] 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 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).

[3] We focus on food access due to data constraints that limit our ability to examine impacts on the other three dimensions of food security.
[4] 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.
[5] 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 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 provides background information on the use of the focal SFM practices in Tanzania. Section 3 outlines the econometric approaches. Section 4 describes the data and food security outcome variables used in this study. The results are presented and discussed in Section 5 and the last section draws conclusions and policy implications.

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 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 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 1, the plot- and HH-level prevalence 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 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)			
4			√	1,384 (25.5)	Sustainable	37.1	39.5
5		√	√	267 (4.9)			
6	√	√		102 (1.9)			
7	√		√	296 (5.5)	SI	8.7	9.4
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.

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).

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 A1); $\overline{\boldsymbol{X}}_{ji}$ 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):

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

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:

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

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:

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

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.[6] 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.[7] 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 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.

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[6] 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.

[7] 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.

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),

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

Nonadopter without adoption (actual),

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

Adopters had they decided not to adopt (counterfactual),

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

Nonadopter had they decided to adopt (counterfactual),

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

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):[8]

$$\begin{aligned} ATT &= E(y_{jit}|U = j, \boldsymbol{Z}_{jit}, \overline{\boldsymbol{Z}}_{ji}, \hat{\boldsymbol{\lambda}}_{jit}) - E(y_{1it}|U = j, \boldsymbol{Z}_{jit}, \overline{\boldsymbol{Z}}_{ji}, \hat{\boldsymbol{\lambda}}_{jit}) \\ &= (\boldsymbol{\beta}_j - \boldsymbol{\beta}_1)\boldsymbol{Z}_{jit} + (\boldsymbol{\delta}_j - \boldsymbol{\delta}_1)\hat{\boldsymbol{\lambda}}_{jit} + (\boldsymbol{\theta}_j - \boldsymbol{\theta}_1)\overline{\boldsymbol{Z}}_{ji}. \end{aligned} \quad (11)$$

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.

[8] 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 A16 of the Appendix.

4 Data and key outcome variables

4.1 Data

This study primarily uses the 2008/09, 2010/11, and 2012/13 TNPS data.[9] 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.[10] 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 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.[11]

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.[12] Among these, we use household distance to the nearest main road, town, and market.[13]

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);[14] (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.[15]

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9 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.

10 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.

11 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).

12 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.

13 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.

14 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.

15 The author thanks Dr. David Mather for sharing these data.

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 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.[16] 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.[17]

Descriptive statistics for the seven outcome variables and control variables used in the analysis are presented in Table 2.[18] 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);[19] and input and proxies for expected output prices (inorganic fertilizer price at district level, lagged prices of maize and rice at the region level, bean and groundnut price at region level).[20]

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16 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.

17 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.

18 A detailed description of the variables and summary statistics by SI category are presented in Appendix Table A1. 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.

19 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.

20 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: Descriptive statistics by survey round

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
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 (cont'd)

Variables	TNPS 2008/09 Mean	SD	TNPS 2010/11 Mean	SD	TNPS 2012/13 Mean	SD	Full sample Mean	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.

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 A2-A8.[21] 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 A9-A15 for the simple falsification test results). The full CRE-MESR regression results for the second stage are reported in Appendix Tables A9-A15. 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 A17, 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 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.

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

Table 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

[21] Since the coefficients reported in Appendix Table A2-A8 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 A18-A24.

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

Outcome variables	SI category	Adoption status: Adopting ($j = 2, 3, 4$)	Adoption status: Nonadopting ($j = 1$)	ATT
		(1)	(2)	(3) = (1) – (2)
Net crop income (1,000 TZS)	Intensification	441.40 (30.62)	232.45 (11.91)	208.95*** (28.99)
(N=3,641)	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)	Intensification	116.52 (4.91)	76.36 (2.00)	40.16*** (4.65)
per acre	Sustainable	108.15 (0.97)	80.89 (0.85)	27.26*** (0.79) SD††
(N=3,641)	SI	114.75 (3.86)	81.09 (1.65)	33.66*** (3.97)
Net crop income (1,000 TZS)	Intensification	102.96 (6.30)	60.55 (2.00)	42.41*** (5.68)
per adult equivalent	Sustainable	81.77 (1.16)	63.12 (0.86)	18.65*** (0.93) SD††
(N=3,641)	SI	120.62 (6.08)	56.99 (1.55)	63.63*** (5.53) SD†
Crop productivity	Intensification	633.22 (19.89)	346.86 (6.97)	286.36*** (18.31)
(N=3,641)	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.

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 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.[22] 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 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 4). These results are consistent with the positive effects of all three of these SI categories on net crop income and productivity in Table 3. They are also consistent with the findings in Table 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 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"

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

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.[23] 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 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.[24] 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.

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23 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.

24 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 4: ATTs of using practices in each SI category on household food access outcomes

Outcome variables	SI category	Adoption status: Adopting	Adoption status: Nonadopting	ATT
		$(j = 2,3,4)$	$(j = 1)$	
		(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.

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 A18-A24) 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.

REFERENCES

Bourguignon, F., Fournier, M., and Gurgand, M. 2007. Selection bias corrections based on the multinomial logit model: Monte Carlo comparisons. *Journal of Economic Surveys* 21(1):174-205.

Bronick, C.J., and Lal, R. 2005. Soil structure and management: a review. *Geoderma* 124:3-22.

Chang, E.C. 2005. Electoral incentives for political corruption under open-list proportional representation. *The Journal of Politics* 67(3):716-730.

Cochrane, N., and D'Souza, A. 2015. Measuring access to food in Tanzania: A food basket approach. EIB-135, U.S. Department of Agriculture, Economic Research Service.

Di Falco, S., and Veronesi, M. 2013. How can African agriculture adapt to climate change? A counterfactual analysis from Ethiopia. *Land Economics* 89(4):743-766.

Di Falco, S., Veronesi, M., and Yesuf, M. 2011. Does adaptation to climate change provide food security? A micro-perspective from Ethiopia. *American Journal of Agricultural Economics* 93(3):829-846.

FAO. 1996. Declaration on the world food security. World food summit, Rome: FAO.

Godfray, H.C.J. 2015. The debate over sustainable intensification. *Food Security* 7(2):199-208.

Godfray, H.C.J., Beddington, J.R., Crute, I.R., Haddad, L., Lawrence, D., Muir, J.F., Pretty, J., Robinson, S., Thomas, S.M., and Toulmin, C. 2010. Food security: the challenge of feeding 9 billion people. *Science* 327(5967):812-818.

Herforth, A., and Harris, J. 2014. Understanding and Applying Primary Pathways and Principles. Brief #1. Improving Nutrition through Agriculture Technical Brief Series. Arlington, VA: USAID/Strengthening Partnerships, Results, and Innovations in Nutrition Globally (SPRING) Project.

Holden, S.T. 2018. Fertilizer and sustainable intensification in Sub-Saharan Africa. *Global Food Security* 18:20-26.

Jaleta, M., Kassie, M., Tesfaye, K., Teklewold, T., Jena, P.R., Marenya, P., and Erenstein, O. 2016. Resource saving and productivity enhancing impacts of crop management innovation packages in Ethiopia. *Agricultural Economics* 47(5):513-522.

Jayne, T.S., Mason, N.M., Burke, W.J., and Ariga, J. 2018. Taking stock of Africa's second-generation agricultural input subsidy programs. *Food Policy* 75:1-14.

Jayne, T.S., Snapp, S., Place, F., and Sitko, N. 2019. Sustainable agricultural intensification in an era of rural transformation in Africa. *Global Food Security* 20:105-113.

Jones, A.D., Ngure, F.M., Pelto, G., and Young, S.L. 2013. What are we assessing when we measure food security? A compendium and review of current metrics. *Advances in Nutrition* 4(5):481-505.

Kassie, M., Marenya, P., Tessema, Y., Jaleta, M., Zeng, D., Erenstein, O., and Rahut, D. 2018. Measuring farm and market level economic impacts of improved maize production technologies in Ethiopia: evidence from panel data. *Journal of Agricultural Economics* 69(1):76-95.

Kassie, M., Teklewold, H., Jaleta, M., Marenya, P., and Erenstein, O. 2015a. Understanding the adoption of a portfolio of sustainable intensification practices in eastern and southern Africa. *Land Use Policy* 42:400-411.

Kassie, M., Teklewold, H., Marenya, P., Jaleta, M., and Erenstein, O. 2015b. Production risks and food security under alternative technology choices in Malawi: Application of a multinomial endogenous switching regression. *Journal of Agricultural Economics* 66(3):640-659.

Khonje, M.G., Manda, J., Mkandawire, P., Tufa, A.H., and Alene, A.D. 2018. Adoption and welfare impacts of multiple agricultural technologies: evidence from eastern Zambia. *Agricultural Economics* 49(5):599-609.

Kim, J., Mason, N.M., Snapp, S., and Wu, F. (in press). Does Sustainable Intensification of Maize Production Enhance Child Nutrition? Evidence from Rural Tanzania. Accepted for publication in *Agricultural Economics* on 8 July 2019.

Kumar, N., Harris, J., and Rawat, R. 2015. If they grow it, will they eat and grow? Evidence from Zambia on agricultural diversity and child undernutrition. *The Journal of Development Studies* 51(8):1060-1077.

Liu, Y., and Myers, R. 2009. Model selection in stochastic frontier analysis with an application to maize production in Kenya. *Journal of Productivity Analysis* 31(1):33-46.

Leroy, J.L., Ruel, M., Frongillo, E.A., Harris, J., and Ballard, T.J. 2015. Measuring the food access dimension of food security: a critical review and mapping of indicators. *Food and Nutrition Bulletin* 36(2):167-195.

Magrini, E., and Vigani, M. 2016. Technology adoption and the multiple dimensions of food security: the case of maize in Tanzania. *Food Security* 8(4):707-726.

Manda, J., Alene, A.D., Gardebroek, C., Kassie, M., and Tembo, G. 2016a. Adoption and impacts of sustainable agricultural practices on maize yields and incomes: Evidence from rural Zambia. *Journal of Agricultural Economics* 67(1):130-153.

Manda, J., Gardebroek, C., Khonje, M.G., Alene, A.D., Mutenje, M., and Kassie, M. 2016b. Determinants of child nutritional status in the eastern province of Zambia: the role of improved maize varieties. *Food Security* 8:239-253.

Marenya, P.P., and Barrett, C.B. 2009. State-conditional fertilizer yield response on western Kenyan farms. *American Journal of Agricultural Economics* 91(4):991-1006.

Mason, N.M., Jayne, T.S., and Van De Walle, N. 2017. The political economy of fertilizer subsidy programs in Africa: Evidence from Zambia. *American Journal of Agricultural Economics* 99(3):705-731.

Mather, D.L., and Jayne, T.S. 2018. Fertilizer subsidies and the role of targeting in crowding out: evidence from Kenya. *Food Security* 10(2):397-417.

Mather, D.L., and Minde, I. 2016. Fertilizer subsidies and how targeting conditions crowding in/out: An assessment of smallholder fertilizer demand in Tanzania. GISAIA/Tanzania Working Paper #5, Michigan State University, East Lansing, MI.

Matson, P.A., Parton, W.J., Power, A.G., and Swift, M.J. 1997. Agricultural intensification and ecosystem properties. *Science* 277(5325):504-509.

McFadden, D. 1973. Conditional logit analysis of qualitative choice behavior. In: Zarembka, P. (Ed.). Frontiers in Econometrics. Academic Press, New York.

Mekuria, M., and Waddington, S.R. 2002. Initiatives to encourage farmer adoption of soil-fertility technologies for maize-based cropping systems in Southern Africa. In C.B. Barrett, F. Place and A.A. Aboud, eds. Natural resources management in African agriculture: Understanding and improving current practices. New York:219-233.

Ngwira, A.R., Aune, J.B., and Mkwinda, S. 2012. On-farm evaluation of yield and economic benefit of short term maize legume intercropping systems under conservation agriculture in Malawi. *Field Crops Research* 132:149-157.

Petersen, B., and Snapp, S. 2015. What is sustainable intensification? Views from experts. *Land Use Policy* 46:1-10.

Pingali, P.L. 2012. Green revolution: impacts, limits, and the path ahead. *Proceedings of the National Academy of Sciences* 109(31):12302-12308.

Pretty, J., Toulmin, C., and Williams, S. 2011. Sustainable intensification in African agriculture. *International Journal of Agricultural Sustainability* 9(1):5-24.

Sauer, C.M., Mason, N.M., Maredia, M.K., and Mofya-Mukuka, R. 2018. Does adopting legume-based cropping practices improve the food security of small-scale farm households? Panel survey evidence from Zambia. *Food Security* 10(6):1463-1478.

Shiferaw, B., Kassie, M., Jaleta, M., and Yirga, C. 2014. Adoption of improved wheat varieties and impacts on household food security in Ethiopia. *Food Policy* 44:272-284.

Smith, J.A., and Todd, P.E. 2005. Does matching overcome LaLonde's critique of nonexperimental estimators? *Journal of Econometrics* 125(1-2):305-353.

Snapp, S.S., and Fisher, M. 2015. "Filling the maize basket" supports crop diversity and quality of household diet in Malawi. *Food Security* 7(1):83-96.

Stahley, K., Slakie, E., Derksen-Schrock, K., Gugerty, M.K., and Anderson, C.L. 2012. Tanzania National Panel Survey LSMS-ISA: Legumes. Evans School Policy Analysis and Research (EPAR) No. 189.

Swindale, A, and Bilinsky, P. 2006 Household dietary diversity score (HDDS) for measurement of household food access: Indicator guide, Academy for Educational Development, Washington, DC.

Tanzania National Bureau of Statistics. 2014. Tanzania National Panel Survey Report (NPS) – Wave 3, 2012-2013, Dar es Salaam, Tanzania, NBS.

Teklewold, H., Kassie, M., Shiferaw, B., and Köhlin, G. 2013. Cropping system diversification, conservation tillage and modern seed adoption in Ethiopia: Impacts on household income, agrochemical use and demand for labor. *Ecological Economics* 93:85-93.

The Montpellier Panel, 2013. Sustainable Intensification: A New Paradigm for African Agriculture. Agriculture for Impact, London.

World Food Programme, 2008. Food consumption analysis: Calculation and use of the food consumption score in food security analysis. Rome: United Nations Vulnerability Analysis and Mapping Branch.

Waddington, S.R., Mekuria, M., Siziba, S., and Karigwindi, J. 2007. Long-term yield sustainability and financial returns from grain legume–maize intercrops on a sandy soil in subhumid north central Zimbabwe. *Experimental Agriculture* 43(4):489-503.

Wooldridge, J.M. 2010. *Econometric Analysis of Cross Section and Panel Data*. MIT Press, Cambridge, MA.

World Bank. 2014. Public expenditure review: national agricultural input voucher scheme (NAIVS).

Zeng, D., Alwang, J., Norton, G.W., Shiferaw, B., Jaleta, M., and Yirga, C. 2015. Ex post impacts of improved maize varieties on poverty in rural Ethiopia. *Agricultural Economics* 46(4):515-526.

APPENDIX

Table A1: 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 A1 (cont'd)

Variables	Variable description	Mean value of each SI category				Mean of all
		N	I	S	SI	
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 A1 (cont'd)

Variables	Variable description	Mean value of each SI category				Mean of all
		N	I	S	SI	
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 A2: 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 A3: 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 A4: 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 A5: 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 A6: 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 A7: 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 A8: 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 A9: 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 A9 (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 A10: 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 A10. (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 A11: 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 A11. (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 A12: 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 A12. (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 A13: 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 A13 (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 A14: 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 A14 (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 A15: 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 A15 (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 A16: 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: Adopting ($j = 2, 3, 4$)	Adoption status: Nonadopting ($j = 1$)	Average treatment effects
		(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 A17: 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: Adopting ($j = 2, 3, 4$)	Adoption status: Nonadopting ($j = 1$)	Average treatment effects
		(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 A18: 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 A19: 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 A20: 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 A21: 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 A22: 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 A23: 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 A24: 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.