Does sustainable intensification of maize production enhance child nutrition? Evidence from rural Tanzania

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Abstract:

Food insecurity, child malnutrition, and land degradation remain persistent problems in sub-Saharan Africa. Agricultural sustainable intensification (SI) has been proposed as a possible solution to simultaneously address these challenges. Yet there is little empirical evidence on if SI do indeed improve child nutrition. To begin to fill this gap, we use Tanzania National Panel Survey data to analyze the child nutrition effects of rural households' adoption of farming practices that contribute to the SI of maize production. We group households into four categories based on their use of three soil fertility management practices on maize plots: "Non-adoption"; "Intensification" (use of inorganic fertilizer); "Sustainable" (use of organic fertilizer, maize-legume intercropping, or both); and "SI" (joint use of inorganic fertilizer with organic fertilizer and/or maize-legume intercropping). The full-sample results from multinomial endogenous treatment effects models suggest that adoption of all three categories improves children's height-for-age z-score (HAZ) relative to "Non-adoption", while only the "SI" category enhances children's weight-for-age z-score (WAZ). Since children are largely breastfed until age 2, we re-estimate the models using children age 25-59 months, which suggests that adoption of "Sustainable" and "SI" categories increases HAZ by 0.44 and 0.38 units, respectively, and WAZ by 0.29 and 0.52 units, respectively.

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1. Introduction

Food insecurity and malnutrition continue to be urgent global problems. Although increases in agricultural productivity have dramatically improved food and nutrition security in many parts of the world over the past five decades, approximately 795 million people worldwide remain undernourished and most of them live in developing countries (FAO 2015). Child malnutrition is an especially serious problem in sub-Saharan Africa (SSA). Globally, about 155 million children under age five suffer from stunting, and more than one third of these children live in SSA (UNICEF, WHO, and World Bank Group 2017). In addition, approximately 45% of global deaths of children under age five are linked to malnutrition, and the mortality rate of children in SSA is the highest in the world (Black et al. 2013).

Agriculture and nutrition are closely linked because the majority of undernourished people still live in rural areas and many of them are smallholder farmers (Sibhatu et al. 2015; Pinstrup-Andersen 2007). Agriculture can affect the level of nutrition of smallholder farming households in primarily two ways: (1) through production of food crops in different quantities and qualities, and at different levels of diversity that households then consume directly; and (2) through the sale of agricultural outputs that influence household incomes and therefore food purchases and consumption (Jones et al. 2014; Hawkes and Ruel 2006). In addition to these main pathways, household incomes may affect women's time and workloads, and the time they devote to child care (Jones et al. 2012). Households with additional income may also raise their expenditures on nutrition-relevant non-food items such as healthcare, sanitation, water, and housing (Shively and Sununtnasuk 2015).

These agriculture-nutrition linkages imply that the adoption of improved farm inputs and management practices at the household level may significantly affect nutritional status of nutritionally vulnerable members, including infants and young children. For the past several decades, the adoption of inputs associated with conventional agricultural intensification such as high-yielding crop varieties and inorganic fertilizer substantially contributed to reductions of food insecurity and poverty in SSA by increasing agricultural productivity (Godfray et al. 2010; Pingali 2012). However, the conventional intensification of agricultural systems might not be sufficient to sustainably raise agricultural productivity and could have negative environmental consequences (Pingali 2012; Kassie et al. 2015a). Moreover, in many parts of SSA, rapidly growing populations and a lack of new land to farm has led to continuous cultivation of plots and reduced fallowing, thereby degrading soils and adversely affecting crop yields (Kassie et al. 2013). In this context, agricultural sustainable intensification (SI) has been drawing attention as a possible solution to simultaneously address nutrition/food security and environmental security challenges (Petersen and Snapp 2015). At the core of SI is the goal of "producing more food from the same area of land while reducing the environmental impacts" (Godfray et al. 2010, p. 813). But more recently, broader definitions of SI extend beyond environmental sustainability to encompass the complex social dimensions of sustainability such as human well-being, including nutritional status and food security (Zurek et al. 2015; Musumba et al. 2017).[1] It is an open

[1]. Loos et al. (2014) argue that narrow definitions of SI are potentially misleading because they inadequately address some central tenets of sustainability such as human well-being. In addition, Musumba et al. (2017) established five domains (productivity, economic, environment, human condition, and social) to assess the degree of sustainability of agricultural intensification. The domain of human condition includes, *inter alia*, individuals' and households' nutritional status and food security. Similarly, Zurek et al. (2015) present the key SI domains (production, food security, environmental sustainability, and income) and provide a tool to visualize trade-offs between SI domains.

question, however, whether agricultural management practices and inputs that contribute to SI from an environmental standpoint do indeed improve the nutrition/food security dimension of SI. Of particular interest in this study are effects on child nutrition. Understanding these relationships for maize production-related inputs and management practices is particularly important in eastern and southern Africa, where maize is the main staple food and is grown by large numbers of smallholder farm households. For example, in Tanzania – the focal country of this study –75% of the total area under cultivation in the country is planted to maize (Tanzania National Bureau of Statistics 2014).

Although SI of maize production has considerable potential to reduce child malnutrition in SSA, there are limited empirical studies that have quantified these relationships. To our knowledge, only Manda et al. (2016a) and Zeng et al. (2017) have empirically estimated the effects of technology adoption associated with SI of maize production on child nutrition, and both studies analyze only the adoption of improved maize varieties. Yet there are numerous other agricultural practices that can contribute to the SI of maize production, and potentially affect child nutrition. This study extends the existing literature by considering three soil fertility management (SFM) practices: the use of inorganic fertilizer, the use of organic fertilizer, and maize-legume intercropping. Given these practices (alone and in combination), we group households into four SI categories for the empirical analysis: "Non-adoption"; "Intensification" (use of inorganic fertilizer only); "Sustainable" (use of organic fertilizer, maize-legume intercropping, or both); and "SI" (joint use of inorganic fertilizer with organic fertilizer and/or maize-legume intercropping). Using nationally representative household panel survey data from Tanzania, we estimate how the adoption of these SI categories affects child nutrition outcomes under age 5 in maize-growing households: height-for-age z-score (HAZ) and weight-for-age z-score (WAZ).

This study further contributes to the existing literature in the following ways. First, to our knowledge it is the first empirical investigation of the impacts of technology adoption on child nutrition in a simultaneous adoption decision framework, which allows us to analyze how combinations of farming practices affect child nutrition. This is based on the observation that farmers are more likely to adopt multiple technologies simultaneously as complements or substitutes rather than adopting them individually (Kassie et al. 2013; Teklewold et al. 2013a; Kassie et al. 2015a). Second, a multinomial endogenous treatment effects model is applied for analysis, which allows us to control for selection bias stemming from both observed and unobserved heterogeneity and to assess the differential impacts of the adoption of single practices versus various combinations of practices (Deb and Trivedi 2006a). Finally, we use panel data whereas the two previous studies most closely related to the current study (Manda et al. 2016a and Zeng et al. 2017) both use cross-sectional data. This enables us to further control for time-invariant unobserved household-level heterogeneity and improve the internal validity of our results, where correlated random effects (CRE)/Mundlak-Chamberlain device techniques are used.

Results suggest that among children aged 0-59 months, adoption of all three SI categories has a positive impact on children's HAZ, while only the "SI" category improves the WAZ in comparison with those in the "Non-adoption" group. The results from regressions with a sub-sample of children beyond breast-feeding age (i.e., those age 25-59 months) further suggest that given the sub-sample means of HAZ and WAZ (i.e., -1.77 and -0.98, respectively), the adoption of the "Sustainable" and "SI" categories increase children's HAZ by 0.44 and 0.38, respectively, and WAZ by 0.29 and 0.52, respectively, on average. The impacts of adoption of the "Intensification" category differ across the samples and nutritional outcome variables.

The remainder of the study is organized as follows. The next section provides background information on sustainable intensification of maize production in Tanzania. Section 3 outlines empirical approaches. Section 4 describes the data and variable specifications, followed by section 5, which presents the empirical results. The last section provides conclusions and implications.

2. Sustainable intensification of maize production in Tanzania

SI focuses on improving the efficient use of resources for agriculture, with the goal of enhancing productivity from the same amount of land while reducing or minimizing the negative environmental impacts. A variety of technologies to support SI have been defined and examined in SSA (Droppelmann et al. 2017; Kassie et al. 2013; Kassie et al. 2015a, b; Manda et al. 2016a; Rusinamhodzi et al. 2012; Teklewold et al. 2013a, b). These include conservation tillage, maize-legume intercropping or rotation, improved crop varieties, animal manure, soil and water conservation, inorganic fertilizer, residue retention as well as their combinations.

In this paper, we analyze three soil fertility management (SFM) practices (alone and in combination) that have the potential to contribute to SI in maize-based systems: (1) inorganic fertilizer, (2) organic fertilizer, and (3) maize-legume intercropping. These practices can be divided into two broad categories: "Intensification" (inorganic fertilizer) and "Sustainable" (organic fertilizer and maize-legume intercropping) (Table 1). Application of inorganic fertilizer is one of the major practices representing conventional agricultural intensification and it has contributed substantially to the tremendous increase in food production globally over the past 50 years (Crews and Peoples 2005; Pingali 2012). However, it is now clear that conventional agricultural intensification can result in negative consequences, such as over-reliance on fossil fuels, reduced biodiversity, and pollution of ground and surface water (Matson et al. 1997; Pingali 2012; Kassie et al. 2015a; Petersen and Snapp 2015). In particular, chemical fertilizer application without the use of complementary soil building practices may lead to a decrease in soil pH, soil organic carbon (SOC), soil aggregation, and microbial communities (Bronick and Lal 2005). This study classifies the sole application of inorganic fertilizer as a practice associated with "Intensification" alone, not SI.

Organic fertilizer in the form of manure or compost is categorized as a "Sustainable" practice because it can be produced in a renewable manner, locally, and enhances soil structure and water retention capacity, encourage the growth of beneficial micro-organisms and earthworms, and decrease bulk density (Chen 2006; Bronick and Lal 2005). However, there are often limitation in terms of locally sourcing large quantities, it has a long-time horizon for observed benefits, and the application of organic fertilizer alone is often not sufficient to substantially raise productivity. Further, it requires investments in livestock as well as labor to recycle organic nutrients (Bandyopadhyay et al. 2010).

Finally, maize-legume intercropping is also categorized as a "Sustainable" practice because it is a local and renewable source of fertility. Moreover, compared to continuous sole-cropped maize, it can improve soil properties for nutrient and moisture holding capacity, and reduce weeds, pests, and diseases (Snapp et al. 2010; Woodfine 2009). Legumes can also benefit household nutrition, providing needed protein and micronutrients such as iron, zinc, or vitamin A (Messina 1999). Because of these benefits, some authors consider maize-legume intercropping to be an SI practice (SIP) (Rusinamhodzi et al. 2012); however, maize yields in certain contexts may be negatively affected by intercropping (Agboola and Fayemi 1971; Waddington et al. 2007) and intercrop systems generally require complementary investments in order to support high crop yields. Relatedly, Dwivedi et al. (2015) suggest that selection of legume crops with different growth durations as well as decisions on when to plant and at what density are essential for an efficient intercropping system. In this study, we consider not specific legumes but all legume crops that are intercropped with maize in Tanzania. Data limitations prevent us from considering planting time and crop density. For all of these reasons, we categorize maize-legume intercropping as a "Sustainable" practice but not sufficient to sustainably intensify maize production.

The three practices considered in this study generate eight possible combinations at the maize plot level and then we group these cases into four categories: "Non-adoption", "Intensification", "Sustainable", and "SI", where "SI" refers to the combined use of "Intensification" (inorganic fertilizer) and at least one of the practices in the "Sustainable" group (organic fertilizer and maize-legume intercropping). For the empirical approach used here (a multinomial endogenous treatment effects model), we need to use the plot-level SI category information to define a household-level SI category variable. This is because multinomial endogenous treatment effects models require that the 'treatment' variable be a mutually exclusive categorical variable. To aggregate the plot-level SI category variable to a household level one, we calculate the household's maize area cultivated under each SI category and then choose the SI category that has the largest area. Table 1 shows the prevalence of these cases and various SI categories on maize plots in Tanzania. Out of 6,383 maize plots pooled across three rounds of survey data, about 38% fall in the "Sustainable" category. The "Intensification" and "SI" categories are much less prevalent, at 7% and 8% of maize plots, respectively. The remaining 47% of maize plots fall in the "Non-adoption" category. Table 1 also shows that the adoption rates of these different categories at the household level are very close to those at the plot level. Approximately 64% of the total maize farmers across the three rounds have only one maize plot, and most maize farmers in Tanzania use the same technologies on all of their maize plots. In fact, 87% of the total maize plots are defined as the same SI category at both the plot and household levels. Among the individual farming practices, maize-legume intercropping is the most common practice used by maize farmers in Tanzania at 38% and 47% at the maize plot and household levels, respectively. The adoption rates of inorganic fertilizer and organic fertilizer are 15% (16%) and 14% (18%), respectively, at the plot level (household level).

Table 1. SI of maize production categories and prevalence on maize plots and among maize-growing households in Tanzania

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

Note: Figures in the plot level column are based on all maize plots (n=6,383) cultivated by rural households pooled across the three waves of the Tanzania National Panel Survey (2008/09, 2010/11, and 2012/13). Figures in the HH level column are based on the total number of maize growers (n=4,269) in rural areas across these surveys. Legume crops for maize-legume intercropping system are beans, soyabeans, groundnut, cowpeas, pigeonpeas, chickpeas, field peas, green gram, bambara nuts, and fiwi.

Source: Authors' calculations.

3. Empirical approaches

This study assumes that farmers are more likely to adopt a combination of technologies as opposed to a single technology to deal with agricultural production constraints such as low crop productivity, droughts, weeds, pests, and diseases. This assumption is more plausible because decision-makers, in reality, are faced with technology alternatives, where one technology can be used as a substitute, complement, or supplement for the other (Kassie et al. 2013; Kassie et al. 2015a). Therefore, ignoring possible inter-relationships between the various practices may under- or over-estimate the influences of various factors on adoption decisions (Wu and Babcock 1998). In addition, farmers may endogenously self-select themselves into an adopter or non-adopter category. If these decisions are influenced by unobservable characteristics (e.g., innate managerial skills and motivation), then endogeneity problems may arise because these unobservable factors may also be correlated with the outcomes of interest (Manda et al. 2016a; Kassie et al. 2015b).

In the literature associated with technology adoption and its impacts, there are several approaches to control selection bias: (1) Zeng et al. (2017) used Instrumental Variable (IV) methods to analyze that adoption of improved maize varieties enhances child nutritional outcomes in Ethiopia but one of the limitations of the IV methods is to impose a linear functional form assumption, indicating the estimated coefficients on the control variables have the same impact for adopters and non-adopters (Ali and Abdulai 2010; Manda et al. 2016a). (2) Another econometric approach to deal with the sample selection bias is propensity score matching (PSM) which requires the strong assumption of unconfoundedness that after observed characteristics are controlled, technology adoption is random and uncorrelated with the outcomes (Abdulai and Huffman 2014). However, systematic differences between outcomes of adopters and non-adopters may still exist even after conditioning observables if the selection depends on unobserved factors (Smith and Todd 2005). To effectively estimate the adoption and impact of SI categories in a multiple adoption setting, we apply the multinomial endogenous treatment effects model proposed by Deb and Trivedi (2006a, b). This model allows us to evaluate alternative combinations of practices as well as individual practices. This framework also captures both self-selection bias and the interdependence of the adoption decisions (Wu and Babcock 1998; Manda et al. 2016b). In addition, correlated random effects (CRE)/Mundlak-Chamberlain device techniques are used to deal with the issue of time-invariant unobserved household-level heterogeneity that may be correlated with observed covariates. To do this, we follow Wooldridge (2010) and include the mean value of time-varying household-level explanatory variables on the right-hand side of each equation.

The multinomial endogenous treatment effects model involves two steps. In the first stage, an individual household *i* chooses one of the four alternatives in the SI category defined in section 2. Following Deb and Trivedi (2006a, b), let EV_{ij}^* denote the indirect utility obtained by household i from selecting the *j*th alternative, $j = 0, 1, 2, \dots, J$ (i.e., $J = 3$ for this study):

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

$\boldsymbol{z}_i$ is a vector of exogenous covariates such as household characteristics, social capital, agricultural characteristics, and input and output prices with associated parameters, $\boldsymbol{\alpha}_j$, to be estimated. η_{ij} are independently and identically distributed error terms. l_{ij} is the latent factor which denotes unobserved characteristics common to household *i*'s adoption of the *j*th alternative and outcome variables (child nutritional status) such as innate managerial skills in understanding new technologies and motivation. Without loss of generality, let *j*=0 denote the control group ("Non-adoption") and $EV_{ij}^* = 0$.

EV_{ij}^* is not directly observed but we observe a binary variable, d_j, representing treatment choice of the SI categories and then let $\boldsymbol{d}_i = (d_{i1}, d_{i2}, \ldots, d_{ij})$. Similarly, let $\boldsymbol{l}_i = (l_{i1}, l_{i2}, \ldots, l_{iJ})$, then the probability of treatment can be expressed as

$$\Pr(\boldsymbol{d}_i|\boldsymbol{z}_i, \boldsymbol{l}_i) = \boldsymbol{g}\left(\boldsymbol{z}_i'\boldsymbol{\alpha}_1 + \delta_1 l_{i1}, \boldsymbol{z}_i'\boldsymbol{\alpha}_2 + \delta_2 l_{i2}, \ldots, \boldsymbol{z}_i'\boldsymbol{\alpha}_J + \delta_J l_{iJ}\right) \tag{2}$$

where $\boldsymbol{g}$ is an appropriate multinomial probability distribution. Following Deb and Trivedi (2006b), we assume that $\boldsymbol{g}$ has a mixed multinomial logit (MMNL) structure defined as

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

In the second stage of the model, we estimate the impact of the adoption of SI categories on two indicators of child nutritional status: height-for-age z-score (HAZ) and weight-for-age z-score (WAZ) using ordinary least squares (OLS) with a selectivity correction term from the first stage. The expected outcome equation is written as

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

where $y_{i,n}$ is the nutrition indicator of interest for child *n* in household *i*. $\boldsymbol{x}_i$ is a set of exogenous covariates including child *n*'s characteristics (e.g., gender of child and age in months) with associated parameter vector $\boldsymbol{\beta}$. Parameters γ_j denote the treatment effects relative to the control group ("Non-adoption"). The expected outcome equation $E\left(y_{i,n}\middle|\boldsymbol{d}_i, \boldsymbol{x}_i, \boldsymbol{l}_i\right)$ is a function of each of the latent factors l_{ij}; that is, the outcome variable is influenced by unobserved characteristics that also affect selection into treatment. If λ_j, known as the factor-loading parameter, is positive (negative), treatment and outcome are positively (negatively) associated with unobserved variables; that is, there is positive (negative) selection, with γ and λ the associated parameter vectors, respectively. This study assumes that the outcome variables (z-scores) that are continuous follow a normal distribution. The model is estimated using a Maximum Simulated Likelihood (MSL) approach.[2]

In principle, the parameters of the semi-structural model through nonlinear functional forms are identified even if all the variables in the adoption equations are identical to those included in the outcome equation; i.e., $\boldsymbol{z}_i = \boldsymbol{x}_i$. However, including some variables in $\boldsymbol{z}_i$ that do not enter in $\boldsymbol{x}_i$ is the preferred approach for more robust identification (Deb and Trivedi 2006a, b). Therefore, we use traditional exclusion restrictions by specifying instrumental variables in the adoption decision model that are excluded from the outcome equation. This study uses both community level and household level information as instrumental variables: the existence of farmer's cooperatives within the community for the community level information; and access to agricultural advice from various sources (government/NGO, cooperatives/large scale farmers), access to agricultural prices from different sources (government/NGO, cooperatives/large scale farmers, radio/TV/publication, neighbor), and input subsidy voucher of inorganic fertilizers for the household level information. All of these variables are likely to encourage the adoption of SI categories because they can improve households' access to inputs and

[2] The model was estimated using the Stata command *mtreatreg* and 500 simulation draws were used.

information on the SFM practices but are unlikely to have any direct effect on child nutritional outcomes. Recent studies also found that these information sources are important drivers of adoption decisions and have used them as instrumental variables in technology adoption studies (Di Falco et al. 2011; Di Falco and Veronesi 2013; Manda et al. 2016a, b). Although there is no formal test for the validity of exclusion restrictions in a nonlinear setting (Deb and Trivedi 2006a), we follow Di Falco et al. (2011) in establishing admissibility of these instruments by performing a simple falsification test, where we anticipate that these variables are likely to be correlated with the adoption of SI categories but is unlikely to affect nutritional outcomes of children among households in the “Non-adoption” group using CRE pooled ordinary least squares regression.

4. Data

The data used for this study come from Tanzania National Panel Survey (TNPS), which is a nationally representative household survey that contains detailed information on the living standards of the population including socioeconomic characteristics, consumption, agricultural production, and non-farm income generating activities. The TNPS is a four-wave panel survey conducted in 2008/09, 2010/11, 2012/13, and 2014/15 but the data from first three rounds are used for empirical analysis because the sample in the fourth wave was refreshed for future rounds. The TNPS is based on a stratified, multi-stage cluster sample design and the clusters within each stratum are randomly selected as the primary sampling units, where there are four different strata: Dar es Salaam, other urban areas on mainland Tanzania, rural mainland Tanzania, and Zanzibar. The TNPS baseline sample of 3,265 households in the first round (TNPS 2008/09) is clustered in 409 enumeration areas.

Our analytical sample consists of rural maize-growing households with children under age 5 (0-59 months). There are 2,242 total household observations meeting these criteria across the three waves of the TNPS (617 observations in 2008/09, 691 in 2010/11, and 934 in 2012/13) and total 3,449 of children under age 5 are included in these households (923 observations in 2008/09, 1,042 in 2010/11, and 1,484 in 2012/13). Table 2 shows child nutritional status under age 5 in our sample and by survey round, where normal status indicates that HAZ (stunting) or WAZ (underweight) are above -2, while moderate or severe status implies that these z-scores are below -2. Out of 3,449 children in our sample, about 42% exhibit stunted growth, while 14% were underweight.

Table 2. Child nutritional status under age 5 in the sample

	TNPS 2008/09		TNPS 2010/11		TNPS 2012/13		Total	
	HAZ (%)	WAZ (%)	HAZ (%)	WAZ (%)	HAZ (%)	WAZ (%)	HAZ (%)	WAZ (%)
Normal (z-score > -2)	478 (51.8)	769 (83.3)	609 (58.4)	883 (84.7)	898 (60.5)	1,311 (88.3)	1,985 (57.6)	2,963 (85.9)
Moderate or severe (z-score < -2)	445 (48.2)	154 (16.7)	433 (41.6)	159 (15.3)	586 (39.5)	173 (11.7)	1,464 (42.4)	486 (14.1)
No. of children under age 5	923		1,042		1,484		3,449	

As mentioned in section 2, although maize growers may have multiple maize plots and employ different sets of SFM practices across plots, the multinomial endogenous treatment effects model requires that we assign each household to a single SI category. This is done by calculating the share of the household's total maize area under each SI category, and then assigning the household to the category that accounts for the largest share of their maize area cultivated. Table 3 shows the prevalence of these household-level SI categories in our sample overall and by survey wave. Of the 2,242 households engaged in maize production pooled over the three rounds, 1,027 households (45.8%) were classified as Non-adoption. The households who use "Sustainable" SI category defined as single or joint use of organic fertilizer and maize-legume intercropping account for 39.9% of the sample. Compared to these two SI categories, the adoption rates of both Intensification (sole use of inorganic fertilizer) and SI (combined use of "Intensification" and "Sustainable" practices) are relatively low, accounting for 6.7% and 7.5% of the observations, respectively. These adoption rates by SI category are similar over time.

Table 3. SI categories adopted by rural maize growers in the sample

SI category	TNPS 2008/09 (%)	TNPS 2010/11 (%)	TNPS 2012/13 (%)	Total (%)
Non-adoption	291 (47.16)	334 (48.34)	402 (43.04)	1,027 (45.81)
Intensification	37 (6.00)	46 (6.66)	67 (7.17)	150 (6.69)
Sustainable	248 (40.19)	249 (36.03)	399 (42.72)	896 (39.96)
SI	41 (6.65)	62 (8.97)	66 (7.07)	169 (7.54)
No. of maize growers	617	691	934	2,242

Note: No. of maize growers refers to the total number of the households with children under age 5 in each wave.

The control variables used in the analysis were selected based on careful reviews of the technology adoption and child nutrition literatures (e.g., Zeng et al. 2017; Manda et al. 2016a, b; Masiye et al. 2010; Alderman et al. 2006; Shively and Sununtnasuk 2015; Apodaca 2008; Teklewold et al. 2013; Kassie et al. 2015a, b; Ndiritu et al. 2014; Falconnier et al. 2016). According to this literature, this study includes child characteristics (age and gender of child, whether or not the child had diarrhea in the past 2 weeks); household characteristics (age and gender of the household head, education level of the household head and female adults, family labor, number of female adults/elderly/child/siblings in the household, marital status of the household head, off-farm income, access to safe drinking water and basic sanitation (toilet)); agricultural characteristics (total cultivated land, own plot, distance to the nearest market, total assets of farm equipment owned by households, livestock ownership); input and output prices (the unit price of inorganic fertilizer paid by farmers and unit market prices of maize, bean, and groundnut); community characteristics (whether or not government health center/hospital is available within the community); and instrumental variables.[3]

[3] The summary statistics of the control variables used in the analysis are not reported to conserve space, but are available from the authors upon request.

5. Empirical results

Factors explaining the adoption of SI categories[4]

To conserve space, we briefly discuss the key factors explaining the adoption of various SI categories, which is the first stage regression of the multinomial endogenous treatment effects model. The results suggest that the education level of the household head, access to off-farm income, more secure land tenure, greater farm assets, livestock owned, market price of maize, (and market distance) are significantly and positively (negatively) correlated with all or some SI categories, which is fairly consistent with previous studies on the adoption of SFM practices/agricultural practices related to SI (Pender and Gebremedhin 2007; Kassie et al. 2013; Kassie et al. 2015a; Manda et al. 2016b; Teklewold et al. 2013a).[5]

As mentioned in Section 3, we performed a simple falsification test to examine the validity of the exclusion restrictions for the instrumental variables. The result suggests that all of the instrumental variables considered in analysis can be validly excluded from the child nutrition outcome equations. More specifically, it shows that the instrumental variables do not affect child nutritional outcomes, both HAZ and WAZ, in households in the "Non-adoption" category. On the other hand, the relevance of the instrumental variables to SI adoption decisions is evident, where all of the instrumental variables are statistically significant determinants of adoption for one or more of the SI categories.

Average treatment effects of the adoption of SI category

The estimates for the average treatment effects of the adoption of the various SI categories on child nutrition outcomes are presented in Table 4. The results are based on the second stage of the multinomial endogenous treatment effects model; the full second stage regression results are reported in the appendix (Table A1).

The full sample results in the upper panel of Table 4 suggest that the child nutrition impacts of adoption of the various SI categories differ across outcome variables. The estimated effects of the "Intensification", "Sustainable" and "SI" categories in the HAZ outcome equation are positive and statistically significant, while the only the "SI" category is statistically significant and positive in the WAZ outcome equation. In addition, there is evidence of selection on unobserved characteristics. The coefficients on the latent factors, λ_S and λ_{SI}, are negative and statistically significant in both the HAZ and WAZ equations, suggesting that unobserved factors that increase the likelihood of adopting the practices in the "Sustainable" and "SI" categories, respectively, are associated with lower levels of child nutritional outcomes. On the other hand, the latent factor, λ_I, is positively and statistically significant in the WAZ equation, implying that unobserved variables increasing the likelihood of adopting inorganic fertilizers only ("Intensification") is associated with higher levels of WAZ.

The estimated coefficients in the multinomial endogenous treatment effects model can be interpreted as changes in the mean outcomes in comparison with those of base category. The results in Table 4 show that, on average, the adoption of inorganic fertilizer only ("Intensification") increases children's HAZ by 0.40 units compared to those in non-adopting households. A similar result is observed for the "SI" group, which consists of joint use of practices in the "Intensification" and "Sustainable" groups. More specifically, adoption of the "SI" increases children's HAZ by 0.34 units

[4] The first stage regressions in the multinomial endogenous treatment effects model and falsification test results are not reported to conserve space, but are available from the authors upon request.
[5] The base category is "Non-adoption" and results in each category are compared with this base category.

relative to "Non-adoption". These are substantial increases given that the sample mean of HAZ is -1.61. The adoption of practices in the "Sustainable" group also positively influences children's HAZ, suggesting this adoption leads to an increase in their HAZ by 1.00 units; however, the magnitude of this effect is very large (perhaps implausibly large), so further analysis is needed. For WAZ, only adoption of "SI" has a statistically significant effect on children's WAZ. On average, adopting the practices in the "SI" group results in a 0.63 unit increase in WAZ for children in these households relative to those in non-adopting households. This is also a large effect given that the average WAZ in the sample is -0.86.

In addition to the full sample analysis (children 0-59 months), we also estimate the models for the sub-sample of children aged 25-59 months. The rationale for the sub-sample analysis is that according to the World Health Organization (WHO 2017), exclusive breastfeeding is recommended up to 6 months of age, with continued breastfeeding along with appropriate complementary/weaning foods up to two years of age. This implies that children age two and under may not be as responsive to food intake because they are exclusively or partially breastfed (Zeng et al. 2017). Re-estimating the models for the sub-sample of children aged 25-59 months enables us to test whether adoption of the various SI categories has different effects on these children than on the broader group of children that includes those that may still be breastfed.[6] The full regression results for the second stage of the sub-sample analysis are presented in the appendix (Table A1) and the main estimates of interest are reported in Table 4. The sub-sample analysis results in Table 4 suggest that adoption of the packages in the "Sustainable" and "SI" categories increases children's HAZ by 0.44 and 0.38 units, respectively, and raises the WAZ by 0.29 and 0.52 units, respectively. These changes are against sub-sample mean HAZ and WAZ values of -1.77 and -0.98, respectively. Adoption of "Intensification" has no statistically significant effect on HAZ or WAZ in the sub-sample. These findings are fairly consistent with the regression results for the full sample except for the "Intensification" category, and provide a more plausible estimate of the positive effect of the "Sustainable" category on HAZ.

The positive effects of "Sustainable" and "SI" adoption on HAZ and WAZ may be explained by two factors. First, the legume crops produced through adoption of maize-legume intercropping, which is included in both the "Sustainable" and "SI" categories, may directly affect the diet composition of adopting households by providing needed protein and micronutrients such as iron, zinc, or Vitamin A (Messina 1999); this, in turn, may positively affect child nutritional outcomes. Second, farmers who adopt two or more practices at once (as is the case for farmers in the "SI" group and some in the "Sustainable" group) might achieve higher maize yields and/or household income than those who do not adopt or that adopt only a single practice (Ndiritu 2014; Manda et al. 2016b; Teklewold et al. 2013b). The increased production and/or income in the households who adopt "Sustainable" and "SI" practices may improve the food availability of the households, food expenditure on high-calorie and protein-rich foods, or non-food expenditures on health services and therefore can enhance child nutrition of the households. On the other hand, a possible explanation for the findings that the adoption of "Intensification" has no statistically significant effects on HAZ and WAZ is that the application of the inorganic fertilizer only ("Intensification") does not involve nutritious legumes suggesting simply producing more maize may not be enough to enhance child nutrition. In addition, although "Intensification" may raise household incomes through increased maize yields, smallholder farmers may still have difficulty directly purchasing legumes on the market because the market prices of legumes such as bean and groundnut are more than three times those of the maize market price. These reasons, therefore, may result in no effects of "Intensification" on HAZ and WAZ.

[6] Ideally, we would also want to estimate the models for the sub-sample of children age 0-24 months; however, there are insufficient observations for such an analysis and the models do not converge.

Table 4. CRE multinomial endogenous treatment effects model estimates: impacts of the adoption of each SI category on child nutritional outcomes

Variables	HAZ	WAZ
Full sample (n=3,449)		
Intensification	0.398**	-0.191
	(0.197)	(0.182)
Sustainable	0.999***	0.054
	(0.252)	(0.122)
SI	0.337**	0.631***
	(0.183)	(0.134)
Selection terms(λ)		
Intensification (λ_I)	-0.339	0.333*
	(0.223)	(0.199)
Sustainable (λ_S)	-1.120***	-0.035
	(0.126)	(0.135)
SI (λ_{SI})	0.327	-0.641***
	(0.220)	(0.160)
Sub-sample: child age > 24 months (n=2,072)		
Dependent variable	HAZ	WAZ
Intensification	-0.208	-0.088
	(0.159)	(0.141)
Sustainable	0.441**	0.289**
	(0.192)	(0.141)
SI	0.384**	0.523***
	(0.154)	(0.120)

Notes: 500 simulation draws were used. Base category is “Non-adoption”. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. Robust standard errors are in parentheses. The selection terms (λ) for the sub-sample analysis are excluded to conserve space.

6. Conclusion and implications

In many developing countries including Tanzania, food insecurity, child malnutrition, and land degradation are serious problems. Agricultural sustainable intensification (SI) has been proposed as a possible solution to address these challenges. Narrowly defined, SI involves increasing agricultural productivity from the same area of land while minimizing or reducing negative environmental impacts. But more recently, broader definitions of SI also include enhancement of human well-being such as nutritional status and food security. Yet there is little empirical evidence on how agricultural technologies that contribute to SI from an environmental perspective affect the human well-being dimensions of SI. Given high rates of child malnutrition in Tanzania and the central role of maize in Tanzanian diets and agricultural systems, we focus here on the relationships between maize soil fertility management practices and child nutritional outcomes. Using rural Tanzania as a case study, we estimate the effects on child malnutrition of the adoption of three SFM practices (i.e., inorganic fertilizer, organic fertilizer, and maize-legume intercropping, alone and in combination) that can promote SI of maize production. In the analysis, we group the combinations of these practices into four SI categories: “Non-adoption”, “Intensification”, “Sustainable”, and “SI”, where “Intensification” is defined as use of inorganic fertilizer only; “Sustainable” is defined as use of organic fertilizer only, maize-legume intercropping only, or their combined use; and “SI” is defined as the combined use of inorganic fertilizer and at least one of the practices in the “Sustainable” group.

Results based on CRE multinomial endogenous treatment effects models suggest that for the full sample of children under age 5 (0-59 months), adoption of all treatment groups (i.e., the “Intensification”, “Sustainable”, and “SI” categories) raises children’s HAZ compared to the “Non-adoption” group, while only the adoption of “SI” raises children’s WAZ. Results based on the sub-sample of children aged 25-59 months (who are less likely to be breastfed and may be more directly affected by household diet changes associated with changes in agricultural practices and production) also suggest positive effects of the “Sustainable” and “SI” categories on HAZ and WAZ. However, adoption of “Intensification” (use of inorganic fertilizer without organic fertilizer and/or maize-legume intercropping) is found to have no statistically significant effects on HAZ and WAZ in this sub-sample. These findings may be because both the “Sustainable” and “SI” categories include maize-legume intercropping, and this may increase the intake of legumes by children in adopting households. On the other hand, while “Intensification” may raise maize yields, increased maize production alone appears to be insufficient to enhance the nutritional outcomes of children beyond breastfeeding age.

Overall, the results suggest that the adoption of maize-legume intercropping, organic fertilizer, or their use in conjunction with inorganic fertilizer on maize plots can substantially enhance child nutrition in rural Tanzania. Our results have several implications for agricultural policy. First, it is important for policy makers to find effective ways to increase adoption of these practices by Tanzanian maize farmers. At present, Tanzania has much lower adoption rates of inorganic fertilizer, organic fertilizer, and maize-legume intercropping than other countries in eastern and southern Africa such as Kenya, Malawi, and Ethiopia (Kassie et al. 2015a). Our results suggest that agricultural extension through both governmental and non-governmental organizations (e.g., farmers’ cooperatives) and input subsidies may be effective strategies to promote and disseminate information about these practices. In addition, the significance of the household head’s education in SI adoption decisions suggests that promoting education may be one mechanism to increase SI in maize-based systems and to reduce child malnutrition.

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Appendix

Table A1. Second stage estimates for child nutritional outcomes

Variables	*Full sample (0-59 months)*		*Sub-sample (25-59 months)*	
	HAZ	WAZ	HAZ	WAZ
Child characteristics				
Child age (months)	-0.016***	-0.012***	0.010***	-0.007***
	(0.002)	(0.001)	(0.003)	(0.002)
Child gender (1=male)	-0.201***	-0.061	-0.137**	0.011
	(0.054)	(0.040)	(0.059)	(0.046)
Diarrhea (1=yes)	-0.329***	-0.180***	-0.274**	-0.105
	(0.085)	(0.064)	(0.111)	(0.095)
Household characteristics				
Head gender (1=male)	0.275*	0.094	0.413**	0.186
	(0.159)	(0.117)	(0.184)	(0.128)
Head age (years)	0.004	0.005	0.012	0.013
	(0.011)	(0.009)	(0.011)	(0.010)
Head education (years)	0.008	0.009	0.005	0.006
	(0.009)	(0.006)	(0.009)	(0.008)
Female education (years)	-0.001	-0.002	0.015	0.005
	(0.009)	(0.007)	(0.010)	(0.008)
Family labor	-0.030	-0.008	0.005	-0.039
	(0.056)	(0.028)	(0.057)	(0.031)
No. of female adults	0.016	-0.016	0.018	-0.064
	(0.106)	(0.078)	(0.108)	(0.091)
No. of elderly	0.216	-0.073	-0.108	-0.150
	(0.292)	(0.239)	(0.350)	(0.266)
No. of child	0.047	0.033	0.017	0.046
	(0.059)	(0.041)	(0.059)	(0.049)
No. of siblings	0.182	0.209*	0.248	0.161
	(0.172)	(0.125)	(0.199)	(0.140)
Head marital status (1=yes)	-0.145	-0.017	-0.273	-0.120
	(0.154)	(0.114)	(0.182)	(0.122)
Off-farm income (1=yes)	-0.013	0.027	0.084	0.143
	(0.126)	(0.101)	(0.143)	(0.124)
Safe drinking water (1=yes)	0.049	0.049	0.069	0.001
	(0.066)	(0.048)	(0.073)	(0.054)
Sanitation (toilet) (1=yes)	-0.186**	-0.039	-0.240***	-0.126**
	(0.073)	(0.053)	(0.079)	(0.061)
Agricultural characteristics				
Total cultivated land (acres)	-0.001	-0.002	-0.005	-0.009
	(0.007)	(0.005)	(0.007)	(0.007)
Own plot (1=yes)	-0.012	-0.047	0.039	0.117
	(0.111)	(0.079)	(0.116)	(0.106)

Table A1. *(Continued)*

Variables	*Full sample (0-59 months)*		*Sub-sample (25-59 months)*	
	HAZ	WAZ	HAZ	WAZ
Market distance (kms)	0.001	0.001	0.002	0.001
	(0.002)	(0.001)	(0.002)	(0.002)
Farm assets (1,000 TSh)	-0.000	-0.000	-0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Livestock (1=yes)	-0.007	0.097**	-0.012	-0.006
	(0.062)	(0.047)	(0.071)	(0.053)
Input and output prices				
Maize price (TSh/kg)	0.000	0.000	0.001***	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Bean price (TSh/kg)	0.000	0.000	-0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Groundnut price (TSh/kg)	0.000***	-0.000	0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Inorganic fertilizer price (TSh/kg)	-0.000	-0.000	-0.000*	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Community characteristics				
Gov. health/hospital (1=yes)	-0.047	0.006	-0.023	-0.012
	(0.054)	(0.040)	(0.060)	(0.048)
SI category				
Intensification	0.398**	-0.191	-0.208	-0.088
	(0.197)	(0.182)	(0.159)	(0.141)
Sustainable	0.999***	0.054	0.441**	0.289**
	(0.117)	(0.122)	(0.192)	(0.141)
SI	0.377**	0.631***	0.384**	0.523***
	(0.183)	(0.134)	(0.154)	(0.120)
Selection terms				
Intensification (λ_I)	-0.339	0.333*	0.239**	0.131
	(0.223)	(0.199)	(0.097)	(0.093)
Sustainable (λ_S)	-1.120***	-0.035	-0.474**	-0.331*
	(0.126)	(0.135)	(0.221)	(0.177)
SI (λ_{SI})	0.327	-0.641***	-0.644***	-0.783***
	(0.220)	(0.160)	(0.185)	(0.151)
Constant	-2.205***	-1.166***	-3.163***	-1.383***
	(0.247)	(0.179)	(0.284)	(0.233)
Observations	3,449	3,449	2,072	2,072

Notes: Sample size is 3,449 individuals for the full sample (2,072 individuals for the sub-sample) and 500 simulation draws were used. For correlated random effects (CRE)/Mundlak-Chamberlain device techniques, time-averages of household level variables to control for time-constant unobserved heterogeneity were included in the model but not reported in Table A1. Base category is “Non-adoption”. ***, **, and * denote statistically significance at the 1%, 5%, and 10% levels, respectively. Robust standard errors are in parentheses.