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Does Sustainable Intensification of Maize Production Enhance Child Nutrition? Evidence from Rural Tanzania

By

Jongwoo Kim, Nicole M. Mason, and Sieglinde Snapp

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AUTHORS

Kim is a PhD student, and Mason is Assistant Professor, Department of Agricultural, Food, and Resource Economics, Michigan State University; Snapp is Professor, Department of Plant, Soil, and Microbial Sciences, Michigan State University.

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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. Narrowly defined, SI entails raising agricultural productivity while preserving or improving the natural resource base, but broader definitions of SI require that it also maintain or enhance human well-being, including child nutrition. Yet there is little empirical evidence on if adoption of practices that contribute to SI from an environmental standpoint do indeed improve child nutrition. To begin to fill this gap, this study uses nationally representative household panel survey data from Tanzania to analyze the child nutrition effects of rural households' adoption of farming practices that contribute to the SI of maize production, an important staple. We consider three soil fertility management practices and group households into four categories based on their use of the practices on their 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). Results from multinomial endogenous treatment effects models combined with the Mundlak-Chamberlain device to control for time invariant unobserved household-level heterogeneity consistently suggest that adoption of practices in the SI category improves children's height-for-age and weight-for-age z-scores relative to Non-adoption, particularly for children age 25-59 months. These findings indicate that SI of maize production may have beneficial effects on child nutrition in maize-growing households in Tanzania.

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ACRONYMS AND ABBREVIATIONS

CRE	Correlated random effects
HAZ	Height-for-age z-score
LSMS-ISA	Living Standards Measurement Study - Integrated Surveys on Agriculture
METE	Multinomial endogenous treatment effects
MMNL	Mixed multinomial logit
MSL	Maximum simulated likelihood
NBS	National Bureau of Statistics
NGO	Non-governmental organization
OLS	Ordinary least squares
SFM	Soil fertility management
SI	Sustainable intensification
SOC	Soil organic carbon
SSA	Sub-Saharan Africa
TNPS	Tanzania National Panel Survey
TSh	Tanzanian shilling
TSh/kg	Tanzanian shilling/kilogram
UNICEF	United Nations Children's Fund
USAID	US Agency for International Development
WAZ	Weight-for-age z-score
WHO	World Health Organization
WHZ	Weight-for-height z-score

1. INTRODUCTION

Food insecurity and malnutrition continue to be urgent global problems. Although increases in agricultural productivity have dramatically improved food and nutrition security in many parts of the world over the past five decades, approximately 795 million people worldwide remain undernourished and most of them live in developing countries (Godfray et al. 2010; FAO, IFAD and WFP 2015; Sibhatu et al. 2015; Koppmair et al. 2016). Hunger and malnutrition are especially serious problems in Sub-Saharan Africa (SSA), where 23.2% of the population is classified as chronically undernourished – the highest prevalence of any region in the world (FAO, IFAD, and WFP 2015). In addition, globally about 155 million children under age five suffer from stunting which is the result of chronic malnutrition and more than one third of these children live in SSA (UNICEF, WHO, and World Bank Group 2017). Malnutrition is a leading cause of worldwide child mortality, making children more vulnerable to severe diseases. 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; UNCS Fund 2014). Child malnutrition also adversely affects physical and mental development, intellectual ability, school performance, future potential labor productivity and wage earnings, and overall economic growth (Manda et al. 2016b; Apodaca 2008). There are several factors that affect child malnutrition in developing countries, including inadequate diet, lack of access to health and sanitation services, parent education, and inadequate care for young children (Alderman et al. 2006; Manda et al. 2016b; Zeng et al. 2017).

Agriculture and nutrition are closely linked because the majority of undernourished people still live in rural areas and many of them are smallholder farmers that rely mainly on family labor (Sibhatu et al. 2015; Pinstrup-Andersen 2007). Agriculture therefore 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 agricultural technologies at the farm household level can play a pivotal role in reducing the level of child malnutrition through higher crop yields and returns. For the past several decades, the adoption of agronomic inputs associated with conventional agricultural intensification such as high-yielding crop varieties, inorganic fertilizer, and pesticides substantially contributed to reduction in food insecurity and poverty in SSA, focusing on increasing agricultural productivity (Godfray et al. 2010; Pingali 2012). However, the 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 improve food security and environmental security (Petersen and Snapp 2015). SI is not just about farming practices or technologies but instead provides an intellectual framework for guiding discussions on gaining balanced outcomes of intensification (Garnett and Godfray 2012). 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).[1] 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; Grabowski et al. 2016a).[2] It is an open question, however, whether agricultural management practices and inputs that improve the environmental dimension of SI positively or negatively contribute to 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). Moreover, maize provides over 40% and 51% of household calories in mainland Tanzania and the southern highlands of Tanzania, respectively (Cochrane and D'Souza 2015). In addition, the most common complementary or weaning foods for children in Tanzania are largely maize-based (Kimanya et al. 2010; Nyaruhucha et al. 2006).

Although SI of maize production has considerable potential to reduce child malnutrition in SSA, there are limited empirical studies that have quantified these relationships. Recent studies on SI mainly assess: (i) the determinants of technology adoption (Arslan et al. 2014; Grabowski et al. 2016b; Kassie et al. 2013; Teklewold et al. 2013a); and (ii) impacts of the adoption on crop yields and household incomes (Teklewold et al. 2013b; Manda et al. 2016a; Kassie et al. 2015b). To our knowledge, only Manda et al. (2016b) and Zeng et al. (2017) have empirically estimated the effects of technology adoption that contributes to 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 individual 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 define four SI categories for the empirical analysis; *Non-adoption*; *Intensification* defined as the use of inorganic fertilizer only; *Sustainable* defined as single or joint use of organic fertilizer and maize-legume intercropping; and *SI* defined as combined use of inorganic fertilizer and at least one of the practices in the Sustainable group (organic fertilizer and 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 investigations 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, which is supported by findings from recent studies (Kassie et al. 2013; Teklewold et al. 2013a; Kassie et al. 2015a). Moreover, Wu and Babcock (1998) argue that ignoring

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[1] Similar definitions have been appeared in Pretty et al. (2011), Montpellier Panel (2013), Falconnier et al. (2015), and Kassie et al. (2015a).

[2] There is a continuing debate over the definition of sustainable intensification. 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, Grabowski et al. (2016a) 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.

interdependence in adoption and impact analysis of technologies may result in under- or over-estimates of the impacts of adoption. Second, a multinomial endogenous treatment effects (METE) 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). This approach is easier to implement compared to the computationally cumbersome multinomial endogenous switching regression model (Manda et al. 2016a) and latent factors incorporated in both treatment and outcome equations allow us to make a distinction between selection on unobservables and selection on observables (Deb and Trivedi 2006a). Finally, we use panel data whereas the two previous studies most closely related to the current study (Manda et al. 2016b and Zeng et al. 2017) both use cross-sectional data. This enables us to further control for unobserved heterogeneity and improve the internal validity of our results, where correlated random effects (CRE)/Mundlak-Chamberlain device techniques are used to control time-invariant unobserved household-level heterogeneity.

Results consistently suggest that, compared to the base category of Non-adoption, adoption of the SI treatment group improves child nutrition (raises children's HAZ and WAZ), particularly for children beyond breast-feeding age (i.e., those age 25-59 months). No such effects are found for younger children (age 6-24 months). The weight of the evidence for the other two treatment groups, Intensification and Sustainable, suggests no statistically significant effects on children's HAZ or WAZ.

The remainder of the study is organized as follows. The next section provides background information on child malnutrition and sustainable intensification of maize production in Tanzania. Section 3 outlines the conceptual and 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. BACKGROUND: CHILD MALNUTRITION AND SUSTAINABLE INTENSIFICATION OF MAIZE PRODUCTION IN TANZANIA

2.1. Child Malnutrition in Tanzania

Chronic child malnutrition remains a persistent problem in SSA and 45% of all deaths of children under age 5 are attributed to undernutrition, including stunting, wasting, fetal growth restriction, and deficiencies of vitamin A and zinc (Black et al. 2013). Tanzania is the third worst affected country in SSA with respect to child malnutrition, exceeded only by Ethiopia and the Democratic Republic of Congo (Muhimbula and Issa-Zacharia 2010). Tanzania also has one of the highest rates of stunting in the region: 35% of children under the age of 5 were moderately or severely stunted as of 2010/11 (Tanzania National Bureau of Statistics 2014).

The nutritional status of a child is usually measured with three indicators: weight-for-age z-score (WAZ), height-for-age z-score (HAZ), and weight-for-height z-score (WHZ). All of these indicators measure nutritional status in the form of z-scores derived by comparing a child's weight-for-age, height-for-age, and weight-for-height, respectively, with that of a reference population of well-nourished children. For example, WAZ is the difference in standard deviations of a child's weight-for-age from the median weight of children in a corresponding age and gender-specific reference group.[3] A child is considered underweight if his/her WAZ is below -2, stunted if his/her HAZ is below -2, and wasted if his/her WHZ is below -2.

Table 1 shows the proportion of underweight, stunted, and wasted children under age 5 in Tanzania based on the Tanzania National Panel Surveys (TNPS) conducted in 2008/09, 2010/11, and 2012/13. The national prevalence of underweight children steadily decreased from 15.9% in 2008/09 to 12.5% in 2012/13. Stunting also declined from 43.0% in 2008/09 to 37.4% in 2012/13. Unlike these two indicators, the proportion of wasted children is relatively low in all three years (at approximately 3-7%). This is a general pattern because both the stunting- and underweight-related z-scores (WAZ and HAZ) reflect long-term factors such as deficiencies in nutrition, frequent infections, and inappropriate feeding practices, while the wasting-related z-score (WHZ) measures current malnutrition and can change quickly over time (Alderman et al. 2006; Tanzania National Bureau of Statistics 2014). For this reason, WAZ and HAZ (and the prevalence of stunting and underweight) are both commonly used in studies on child malnutrition. However, HAZ (stunting) is preferred because WAZ (underweight) is a composite measure of HAZ (stunting) and WHZ (wasting), making interpretation of WAZ (underweight) difficult.

Table 1. Trends in the Malnutrition Status of Children under Age 5 in Tanzania

	Underweight (%) (WAZ < -2)			Stunting (%) (HAZ < -2)			Wasting (%) (WHZ < -2)		
	2008/09	2010/11	2012/13	2008/09	2010/11	2012/13	2008/09	2010/11	2012/13
Tanzania	15.9	13.6	12.5	43.0	34.8	37.4	2.7	6.6	4.2
Urban	9.8	9.2	9.3	30.2	24.1	29.5	1.5	5.9	4.3
Rural	17.1	14.6	13.3	45.6	37.2	39.3	2.9	6.8	4.2

Source: Tanzania National Bureau of Statistics 2014.

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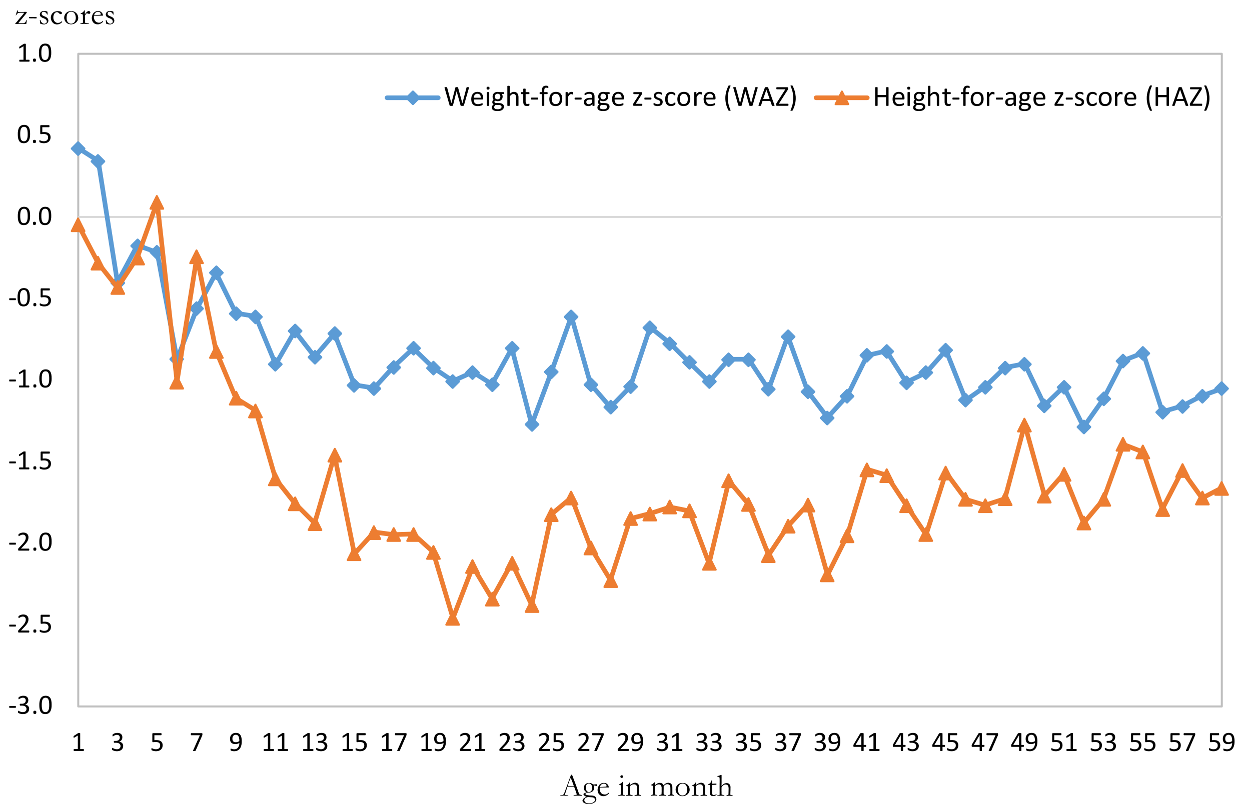
[3] To calculate child nutritional status (z-scores), this study used the WHO Child Growth Standards and WHO Reference 2007 composite data files as the reference data.

Table 1 also shows that child malnutrition rates are remarkably different between urban and rural areas: all the malnutrition rates in rural areas are consistently higher than in urban areas except wasting in 2012/13. In the reminder of the paper we concentrate on both HAZ/stunting, and WAZ/underweight.

With respect to WAZ and HAZ, the growth faltering patterns of children in resource-poor countries differ considerably by age. According to Victora et al. (2010) and based on 54 low-income countries in Africa and Southeast Asia, rapid growth faltering of HAZ was observed until 24 months of age, then plateauing from 25- 59 months, while WAZ showed progressive and slow faltering through months 0-59, with the most rapid declines from 0-24 months. These findings have been influential in developing the concept of the "critical window of opportunity" – the 1,000 days from conception through the first two years of life – for preventing child malnutrition within which growth promoting nutritional interventions should be focused (Prentice et al. 2013). Figure 1 shows mean WAZ and HAZ by children's age in months (0-59) based on the 2008/09, 2010/11, and 2012/13 waves of the TNPS. The growth faltering patterns in Tanzania are similar to those in Victora et al. (2010). Because the nutritional effects of agricultural interventions or technology adoption may differ across ages, we explore the effects of use of the various SI categories on nutritional outcomes of children in different age groups.

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



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

2.2. 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. More precisely, SI excludes extensification, i.e., bringing more land into agriculture, since land conversion for agriculture has negative consequences to the public good by generating greenhouse gases, for example (Godfray 2015). In addition, bringing more land into agriculture becomes increasingly restricted because of the pressure of rising population and competition for land from other human activities such as urbanization (Godfray et al. 2010). 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. 2016b; Rusinamhodzi et al. 2012; Teklewold et al. 2013a, b; Ortega et al. 2016). 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. Falconnier et al. (2016) suggest two strategies to sustainably intensify cereals production in SSA: (1) integrated soil fertility management defined as the use of improved crop varieties along with inorganic fertilizer, organic resource management, and other soil amendments; and (2) crop diversification through cereal-legume rotations or cereal-legume intercropping.

In this paper, we analyze three 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 2).[4] 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). Further, it requires reliance on externally sourced, fossil-fuel products with substantial associated transportation costs. 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).

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[4] There are several farming practices and inputs commonly used for maize production in Tanzania: use of inorganic fertilizer, organic fertilizer, intercropping, and improved maize varieties (Tanzania National Bureau of Statistics 2014). While some previous studies consider the use of improved maize varieties to be a form of intensification, maize growth and yields are significantly influenced by plant population density (Adeniyan 2014; Abuzar et al. 2011), which is not adequately captured in the data used in this study (the TNPS). Moreover, the first two rounds of the TNPS do not distinguish between first generation improve varieties and recycled ones. Given these data limitations, use of improved maize varieties is not included as an intensification practice in this study.

Table 2. 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

Source: Authors' calculations.

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, cow peas, pigeon peas, chick peas, field peas, green gram, bambara nuts, and fiwi.

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; Tilman et al. 2002; Woodfine 2009). Pigeon pea, for example, is often intercropped with maize in Tanzania to maximize land use, spreading economic risk and improving crop yields through nitrogen fixation (Amare et al. 2012; Høgh-Jensen et al. 2007). Pigeon pea and other legumes can also benefit household nutrition, providing needed protein and micronutrients such as iron, zinc, or vitamin A (Messina 1999).

Because of these benefits, some authors consider maize-legume intercropping to be an SI practice (Rusinamhodzi et al. 2012); however, maize yields in certain contexts may be negatively affected by intercropping (Agboola and Fayemi 1971; Waddington et al. 2007) and intercrop systems generally require complementary investments in order to support high crop yields. 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: beans, soyabeans, groundnuts, cow peas, pigeon peas, chick peas, field peas, green grams, bambara nuts, and fiwi. 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 (inorganic fertilizer, organic fertilizer, and maize-legume intercropping) generate eight possible combinations at the maize plot level (Table 2). We group these cases into four categories (defined as SI categories in Table 2): 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 (an METE model), we need to use the plot-level SI category information to define a household-level SI category variable.[5] This is because METE models require that the *treatment* variable be a mutually exclusive categorical variable. We then estimate the effects of the household-level SI category on the nutrition outcomes of children in the household. 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 2 shows the prevalence of these cases and SI categories on maize plots in Tanzania. Out of 6,383 maize plots pooled across three rounds of survey data (TNPS 2008/09, 2010/11, and 2012/13), 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 2 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 2).

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[5] Future iterations of this paper will use additional methods that allow a given household to be in multiple SI categories.

3. CONCEPTUAL AND ECONOMETRIC FRAMEWORK

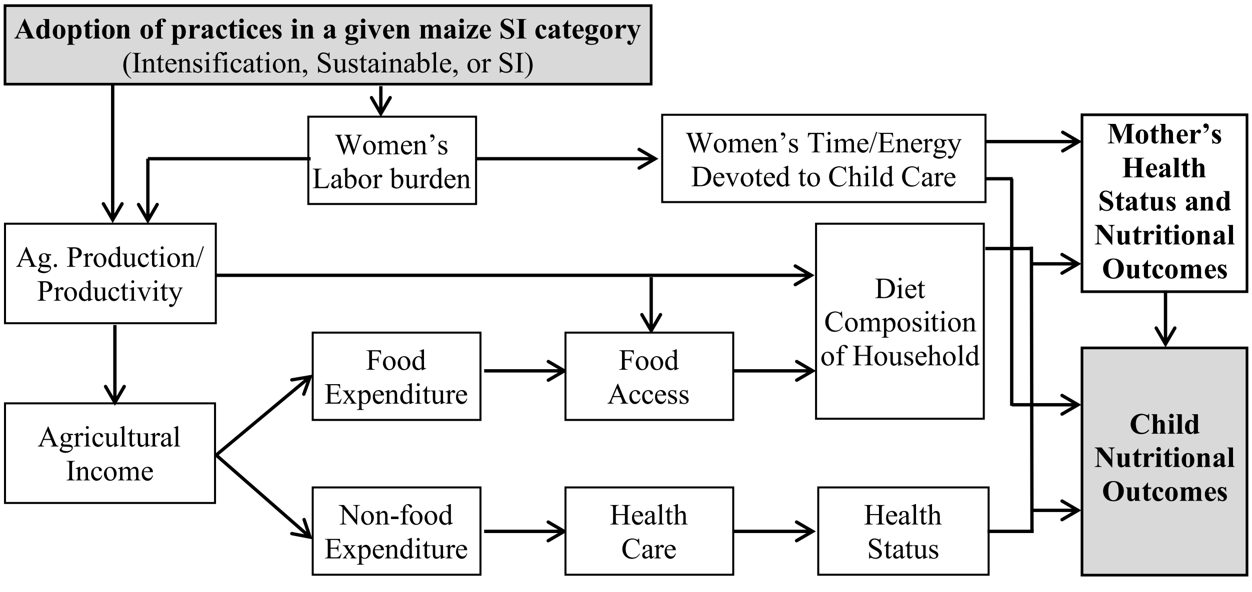
3.1. Conceptual Framework

Figure 2 depicts the main pathways through which the adoption of SFM practices on maize plots and sustainable intensification of maize production might improve child nutritional outcomes. First, the adoption of SI categories may directly increase food production and/or productivity, and consequently, the availability of food for the household. Increased production can also influence food prices in local markets and therefore affect a household's food expenditure. In addition to providing more food, the adoption of maize-legume intercropping may directly affect the diet composition of households by providing leguminous crops with a range of essential nutrients. As the other major pathway, the adoption of SFM practices/SI categories is expected to increase household income through the sales of surplus crops, which, in turn, could raise expenditures on high calorie and protein-rich foods as well as non-food expenditures on health services, sanitation, and access to clean water. Moreover, increased productivity and household income may reduce women's labor burden, which could enable them to spend more time caring for infants and young children.

3.2. Multinomial Endogenous Treatment Effects (METE) Model

This paper 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. Recent studies in SSA also found that some practices used in maize production are complementary while other are substitutable (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; Kassie et al. 2013). In addition, farmers may endogenously self-select themselves into an adopter or non-adopter category.

Figure 2. Conceptual Pathways between SI of Maize Production and Child Nutritional Outcomes



Source: Authors, adapted from Herforth and Harris (2014).

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. 2016b; Kassie et al. 2015b).

In this study, we focus on the adoption of three SFM practices, inorganic fertilizer, organic fertilizer, and maize-legume intercropping, alone and in combination, that contribute to SI of maize production and then generate four SI categories: Non-adoption, Intensification, Sustainable, and SI. To effectively estimate the adoption and impact of SI categories in a multiple adoption setting, we apply the METE 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; Kassie et al. 2015b). 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 METE model involves two steps. In the first stage, a farmer chooses one of the four SI categories and the farmer's choice is modeled in a mixed multinomial logit selection model. In the second stage of the model, the impacts of each SI category on the outcome variables (child nutritional status) are estimated using ordinary least squares (OLS) with a selectivity correction term from the first stage. In the first stage of the model, an individual household *i* chooses one of the four alternatives in the SI category mentioned above. Following Deb and Trivedi (2006a, b), let EV_{ij}^* denote the indirect utility obtained by household *i* from selecting the *j*th alternative, $j = 1, 2, \dots, J$ (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 $\boldsymbol{d}_i = (d_{i1}, d_{i2}, \dots, d_{ij})$. Similarly, let $\boldsymbol{l}_i = (l_{i1}, l_{i2}, \dots, l_{iJ})$, then the probability of treatment can be expressed as

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

where g is an appropriate multinomial probability distribution. Following Deb and Trivedi (2006b), we assume that 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, 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). 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 vector of exogenous covariates including two sub-vectors: household *i*'s characteristics $\boldsymbol{h}_i$ and child *n*'s characteristics $\boldsymbol{c}_{i,n}$. The associated parameter vector is $\boldsymbol{\beta}$. Parameters γ_j 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 $\boldsymbol{l}_{ij}$; that is, the outcome variable is influenced by unobserved characteristics that also affect selection into treatment. If $\boldsymbol{\lambda}_j$, 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 $\boldsymbol{\gamma}$ and $\boldsymbol{\lambda}$ 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.[6]

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. In this study, we use both community level and household level information as instrumental variables: the existence of farmer's cooperatives within the community as the community level information; and access to agricultural advice from cooperatives/large scale farmers and receipt of an input subsidy voucher of inorganic fertilizers as 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 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. These variables should be correlated with the adoption of SI categories but should not affect the nutritional outcomes of children in households in the Non-adoption category. This falsification test regressions are estimated via CRE pooled ordinary least squares.

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

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 fourth wave of the survey was refreshed for future rounds. All four rounds of the TNPS were implemented by the Tanzania National Bureau of Statistics (NBS) in conjunction with the World Bank.[7] 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.[8] The original sample of 3,265 households and their members were tracked and re-interviewed in the second (TNPS 2010/11) and third rounds (TNPS 2012/13): the second round of the TNPS tracked 97% of the original households in the first round and the third round of TNPS tracked 96% of the households in second round, giving very low attrition rates between the rounds (Tanzania National Bureau of Statistics 2014).

We srart with observations of children under age 5 (0-59 months) in rural households that grew maize in the main farming season (i.e., the long-reainy season) in a given wave but drop children who were not born at the time their household started harvesting their maize because they are less likely to be affected by their household's SI adoption decision. There are 2,055 total household observations meeting these criteria across the three waves of the TNPS (579 observations in 2008/09, 623 in 2010/11, and 853 in 2012/13) and total 2,898 of children under age 5 are included in these households (794 observations in 2008/09, 862 in 2010/11, and 1,242 in 2012/13). Table 3 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. To calculate these nutritional indicators, we used anthropometric data such as height and weight which are directly available in TNPS and a child age in month was calculated by subtracting his/her month of birth from the time when the data were collected. The proportions of stunted or underweighting children measured in this study are very similar with those of rural areas in Table 1. Out of 2,898 children in our sample, about 46% exhibit stunted growth, while 15% were underweight.

Table 3. 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)	395 (49.8)	658 (82.9)	461 (53.5)	719 (83.4)	713 (57.4)	1,090 (87.8)	1,569 (54.1)	2,467 (85.1)
Moderate or severe (z-score < -2)	399 (50.2)	136 (17.1)	401 (46.5)	143 (16.6)	529 (42.6)	152 (12.2)	1,329 (45.9)	431 (14.9)
No. of children under age 5	794		862		1,242		2,898	

Source: Authors' calculations based on the analytical sample.

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[7] The TNPS is provided by World Bank through the Living Standards Measurement Study – Integrated Surveys on Agriculture (LSMS-ISA) program.

[8] In each stratum, clusters were randomly chosen based on their probability proportional to population size. In urban areas, a cluster refers to a census enumeration area based on the 2002 Population and Housing Census, while in rural areas an entire village was defined as a cluster.

As mentioned in Section 2, although maize growers may have multiple maize plots and employ different sets of SFM practices across plots, the METE 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 4 shows the prevalence of these household-level SI categories in our sample overall and by survey wave. Of the 2,055 households engaged in maize production pooled over the three rounds, 941 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 40.2% 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 6.6% and 7.4% of the observations, respectively. These adoption rates by SI category are similar over time.

Table 5 provides summary statistics of the control variables used in the analysis. These variables 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, mother's education, monthly difference between maize harvest and collection of anthropometric data, dummy variables for frequency of the child across survey rounds); household characteristics (age and gender of the household head, education level of the household head and spouse, family labor, number of female adults/elderly/child/siblings in the household, marital status of the household head, off-farm income, access to a safe drinking water source and use of safe drinking water, basic sanitation (toilet)); agricultural characteristics (total cultivated land, maize plot ownership, distance to the nearest market, total assets of farm equipment owned by households, and livestock ownership); input and output prices; community characteristics (whether or not government health center/hospital is available within the community); and instrumental variables. To analyze the effects of input and output prices on the adoption decision and child nutritional status, this study includes the unit price Tanzanian shilling/kilogram (TSh/kg) of inorganic fertilizer paid by farmers and unit market prices (TSh) of maize, bean, and groundnut, where each price is collected at the district level.[9]

Table 4. SI Categories Adopted by Rural Maize Growers in the Sample

SI category	TNPS 2008/09 (%)	TNPS 2010/11 (%)	TNPS 2012/13 (%)	Total (%)
Non-adoption	272 (46.98)	299 (47.99)	370 (43.38)	941 (45.79)
Intensification	35 (6.04)	40 (6.41)	61 (7.15)	136 (6.62)
Sustainable	235 (40.59)	228 (36.60)	363 (42.55)	826 (40.19)
SI	37 (6.39)	56 (9.00)	59 (6.92)	152 (7.40)
No. of maize growers	579	623	853	2,055

Source: Authors' calculations based on the analytical sample.

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

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[9] Among various legume crops, the market prices of two legumes, bean and groundnut, are considered in this study because they are the most common legumes intercropped on maize plots in Tanzania; approximately 50% and 20% of maize-legume intercropped plots involve bean and groundnut, respectively. The next most common legumes are pigeon pea and cow pea but price information on these crops is not available in TNPS.

Table 5. Summary Statistics of the Variables Used in the Analysis

Variables	Variable description	Mean	Std. dev.
Child Nutritional Status			
HAZ	Height-for-age z-score	-1.78	1.36
Stunting	1=yes if HAZ < -2	0.46	0.50
WAZ	Weight-for-age z-score	-0.96	1.06
Underweight	1=yes if WAZ < -2	0.15	0.36
Control Variables			
Child Characteristics			
Child age	Age of children under age 5 (months)	34.56	14.46
Child gender	1 = male	0.49	0.50
Diarrhea	1 = yes if the child had diarrhea in the past 2 weeks	0.10	0.30
Mother's education	Highest grade completed bythe child's mother (years)	4.65	3.43
Monthly difference	Time difference between maize harvest and measurement of the child's nutritional status (months)	10.02	4.13
T1 dummy (excluded)	1=yes if the child is observed once in any of three waves	0.61	0.49
T2 dummy	1=yes if the child is observed twice in any of three waves	0.38	0.49
T3 dummy	1=yes if the child is observed in all of three waves	0.01	0.11
Household Characteristics			
Head gender	Gender of the household head (1 = male)	0.83	0.37
Head age	Age of the household head (years)	43.65	14.24
Head education	Highest grade completed by the household head (years)	4.78	3.33
Spouse education	Highest grade completed by the spouse	4.04	3.40
Family labor	Number of adults (15-64 years old) per acre	1.07	1.40
No. of female adults	Number of female adults in the household	1.62	1.05
No. of elderly	Number of household members above 65 years	0.21	0.50
No. of child	Number of household members below 15 years	3.76	2.15
No. of siblings	Number of siblings of children under age 5	0.06	0.33
Head marital status	1 = yes if the HH head got married	0.70	0.46
Off-farm income	1 = yes if the HH earns other income	0.47	0.50
Access to safe drinking water source	1 = yes if the HH has safe drinking water source (e.g., piped or protected water)	0.23	0.42
Safe drinking water	1 = yes if the HH does drink boilded/bottled/treated water	0.24	0.43
Sanitation (toilet)	1 = yes if the HH has a private toilet	0.81	0.39
Agricultural Characteristics			
Total cultivated land	Total land area (acres) cultivated	7.23	18.38
Own plot	1 = yes if the HH owns any maize plot	0.92	0.27
Market distance	Distance to the nearest market (kms)	11.84	13.27
Farm assets	Total assets of farm implements and machinery (1,000 TSh)	1,903.38	8,720.10
Livestock	1 = yes if the HH has livestock (cattle, goats/sheep, pig, and donkey)	0.49	0.50

Table 5. cont.

Variables	Variable description	Mean	Std. dev.
Input and Output Prices			
Maize price	Maize (grain) market price at district level (TSh/kg)	470.41	203.85
Bean price	Bean market price at district level (TSh/kg)	1301.01	323.03
Groundnut price	Groundnut market price at district level (TSh/kg)	1683.53	561.07
Inorganic fertilizer price	Inorganic fertilizer price at district level (TSh/kg)	1125.33	409.42
Community Characteristics			
Gov. health/hospital	1 = yes if governmental health center/hospital is available within the community	0.44	0.50
Instrumental Variables			
Cooperatives	1 = yes if farmer's cooperatives are within the community	0.41	0.49
Extension from coop.	1 = yes if the HH received agricultural advice from cooperative/large scale farmer in the past 12 months	0.05	0.21
Input subsidy voucher	1=yes if the HH received a voucher for any of inorganic fertilizer	0.05	0.22

Source: Authors.

Note: TSh = Tanzanian Shillings. The means and standard deviations for child characteristics are based on the individual (children) level data (n=2,898). On the other hand, the means and standard deviations for the others (household and agricultural characteristics, input and output prices, community characteristics, and instrumental variables) are calculated based on the sample households (n=2,055).

5. EMPIRICAL RESULTS

5.1. First Stage and Falsification Test Restuls

The first stage results are reported in Appendix Table A1. Of particular interest are the effects of the IVs on the adoption of the various SI categories. All three IVs have positive and highly statistically significant effects on adoption of Intensification and SI practices relative to Non-adoption but do not have statistically significant effects on adoption of Sustainable practices. This makes sense given that the input subsidy voucher was for inorganic fertilizer and improved maize (or rice) seed, and inorganic fertilizer is included in the Intensification and SI groups. The results of the simple falsification test for the IVs are reported in Appendix Table A2. These results suggest that the IVs do not directly affect the HAZ or WAZ of children in households in the Non-adoption category, which supports the validity of the exclusion restrictions.

5.2. 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 6. The results are based on the second stage of the METE model; the full second stage regression results are reported in Appendix Table A3.

The full sample results (children age 0-59 months at the maize harvest) in the upper panel of Table 6 suggest that the child nutrition impacts of adoption of the various SI categories differ across outcome variables. The estimated effects of the SI treatment group in both the HAZ and WAZ outcome equations are positive and statistically significant, while the Intensification category is negatively associated with the HAZ but not WAZ. In addition, there is evidence of selection on unobserved characteristics as indicated by the statistically significant latent factors for some SI category-nutrition outcome pairs.

The estimated coefficients from the METE model can be interpreted as changes in the mean outcomes in comparison with those of base category. Therefore, the results in the first panel of Table 6 show that, on average, adoption of the SI category increases children's HAZ and WAZ by 0.60 units and 0.43 units, respectively, compared to those in non-adopting households. These are sizeable increases relative to the sample mean HAZ and WAZ of -1.78 and -0.96, respectively. In contrast, the results suggest that the adoption of the inorganic fertilizer use only (Intensification) is associated with a decrease in children's HAZ of 0.54 units. However, this result is counter-intuitive because the use of inorganic fertilizer is expected to raise maize yields relative to the Non-adoption group, which we expect to either positively affect child nutrition outcomes or have no statistically significant effect. We therefore treat this result with caution and as shown below, this finding is not robust to the model specification.

In addition to the full sample analysis, we also estimate the models for sub-samples of children in different age groups: (i) children aged 6-59 months at the maize harvest (Sub-sample 1); and (ii) children aged 25-59 months at the maize harvest (Sub-sample 2).[10] As mentioned in Section 2, the major rationale behind the sub-sample analyses is that the growth faltering patterns of children under age 5 differ across ages; as a result, the child nutritional impacts of SI adoption decisions may also vary. More specifically, we drop children age 0-5 months for Sub-sample 1 because they are typically exclusively breastfed during that period (Tanzania Food and Nutrition Centre 2014) and thus less likely to be directly affected by diet changes associated with SI adoption. We also include in the Sub-sample 1 model interaction terms between the SI treatment groups and an indicator variable

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[10] The first stage regressions for the sub-sample analyses are available from the authors upon request. The full regression results for the second stage in the METE model are presented in the appendix (Table A3).

of children age 6-24 months. This allows us to examine differential effects of the SI treatment groups on the nutritional outcomes of the children who are in the "critical window" for the promotion of optimal growth, health, and development.[11] The results from Sub-sample 1 are presented in the middle of Table 6 and suggest that the adoption of practices in the SI group increases children's HAZ and WAZ by 0.33 and 0.61 units, respectively, and that the adoption of the Sustainable group increases HAZ by 0.60 units. However, we do not find evidence of statistically significant child nutrition effects for any of the SI treatment groups for children age 6-24 months. This result may be because children age 6-24 months may still be breastfed and largely dependent on complementary/weaning foods instead of consuming adult foods (Zeng et al. 2017; Tanzania Food and Nutrition Centre 2014; Stephenson et al. 2017).[12] Consistent with our findings, a recent study (Jain 2018) finds that nutrient intake – whether the quantity or the quality of food – has no association with the HAZ of children aged 6-23 months in rural Bangladesh, while maternal body mass index (BMI) and education level are more important determinants of these children's HAZ.

The results for Sub-sample 2 (children age 25-59 months) are reported in the bottom panel of Table 6. These results suggest that adoption of practices in the SI group increases children's HAZ by 0.36 units and raises WAZ by 0.58 units. These findings are consistent with the Sub-sample 1 results in terms of the level of impacts for the SI group but the coefficient on the Sustainable group is no longer statistically significant. The robust finding across the three specifications reported in Table 6 is that the SI treatment group is associated with increases in children's HAZ and WAZ, particularly among children age 25-59 months, relative to Non-adoption.

In addition to the main results reported in Table 6, we perform a robustness checks by including two variables associated with maternal characteristics (mother's age and BMI), which are also key factors affecting child nutritional status but are excluded in our main model specification (Black et al. 2013; Jain 2018). One reason for excluding these variables is that information on these variables is missing for approximately 12% of the sample (mainly for children whose biological mother passed away or does not reside in the same household). The other reason is that the mother's BMI could be affected if the mother is pregnant, but we do not have information on if the mother is pregnant. This study, therefore, uses mother's age and BMI only for the robustness checks; the associated main estimates of interest are presented in Appendix Table A4. These results suggest that the mother's age and BMI are positively correlated with one or both child nutrition outcomes. Moreover, we still consistently find that use of practices in the SI group are statistically significant and positively correlated with both HAZ and WAZ.

Overall, the robust finding in this study is that the adoption of the SI treatment group substantially improves both HAZ and WAZ. This may be explained by three factors. First, the legume crops produced through adoption of maize-legume intercropping, which is included in the SI category, 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. A recent study (Stahley et al. 2012) reports that producing households in Tanzania consume twice the quantity of legumes (i.e., beans, peas, and groundnut) as purchasing households. Furthermore, these legume crops could help farmers to increase their agricultural income since per-kilogram sale prices for legumes such as beans and groundnuts are relatively high compared to maize prices (see Table 5). Second, relative to farmers who do not adopt any of the practices or farmers that adopt only one practice, farmers in the SI group adopt two or three practices at once. This may result in higher maize yields, crop output (e.g., maize and legumes for

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

[12] A recent study (Stephenson et al. 2017) finds that the addition of cowpea to complementary feeding of Malawian infants aged 6-12 months resulted in significantly less stunting.

those that intercrop and use inorganic fertilizer), and/or household income due to synergistic effects between practices (e.g., organic and inorganic fertilizer) (Waddington et al. 2007; Mekuria and Waddington 2002; Ndiritu 2014; Manda et al. 2016b; Teklewold et al. 2013b). The increased production and/or income in the households who adopt packages in the SI group 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 (per Figure 2). Finally, the adoption of packages in the SI group could result in increased maize yields and yield response to inorganic fertilizer through synergistic effects when organic manure is used jointly with inorganic fertilizer (Place et al. 2003; Schoebitz and Vidal 2016). (Recall that inorganic fertilizer used jointly with organic manure is one of the combinations in the SI group.) Relatedly, a recent field experimental study (Mahmood et al. 2017) finds that growth and yields of maize are substantially improved by the combined use of inorganic fertilizers and organic manures compared to sole application of organic or inorganic fertilizer.

Potential explanations for the statistically insignificant effects of Intensification on HAZ and WAZ in most of the models are that the application of the inorganic fertilizer only (Intensification) does not involve nutritious legumes, and simply producing more maize (as a result of inorganic fertilizer use) may not be enough to enhance child nutrition. Similarly, the largely statistically insignificant effects for packages in the Sustainable group may be because although these practices could improve overall soil fertility in the long term, they may not be sufficient to substantially raise crop yields or incomes in the short-run and thus may not be enough improve children's nutritional status in the short-run.[13]

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[13] Stahley et al. (2012) find based on the TNPS data that legume yields per unit of land (ha) are lower on intercropped plots relative to non-intercropped plots. Median maize yields are also lower on the intercropped plot with legumes (0.66 t/ha) compared to pure maize plots (0.79 t/ha).

Table 6. CRE METE Model Estimates: Impacts of the Adoption of Each SI Category on Child Nutritional Outcomes

Variables	HAZ	WAZ
Full Sample (n=2,898): children aged 0-59 months at the maize harvest		
Intensification	-0.535***	-0.038
	(0.155)	(0.309)
Sustainable	0.130	0.128
	(0.150)	(0.370)
SI	0.598***	0.426**
	(0.135)	(0.175)
Selection Terms (λ)		
Intensification (λ_I)	0.751***	0.200
	(0.130)	(0.335)
Sustainable (λ_S)	-0.076	-0.097
	(0.157)	(0.443)
SI (λ_{SI})	-0.783***	-0.487**
	(0.101)	(0.216)
Sub-sample 1(n=2,560): children aged 6-59 months at the maize harvest		
Intensification	-0.103	-0.110
	(0.192)	(0.223)
Sustainable	0.599***	0.148
	(0.203)	(0.304)
SI	0.332**	0.607***
	(0.152)	(0.122)
Intensification×6-24 months of age	-0.139	-0.075
	(0.228)	(0.173)
Sustainable×6-24 months of age	0.188	0.030
	(0.117)	(0.088)
SI×6-24 months of age	0.112	0.073
	(0.172)	(0.146)
Sub-sample 2(n=1,453): children aged 25-59 months at the maize harvest		
Intensification	-0.210	-0.207
	(0.199)	(0.198)
Sustainable	-0.139	0.031
	(0.140)	(0.125)
SI	0.360*	0.576***
	(0.186)	(0.113)

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 analyses 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 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. This study adds to the very thin literature on this topic by estimating the effects on child malnutrition of the adoption of three SFM practices (inorganic fertilizer, organic fertilizer, and maize-legume intercropping), alone and in combination, that can contribute to 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.

The results, which are derived from CRE METE models, consistently suggest that adoption of the SI treatment group raises children's HAZ and WAZ compared to the Non-adoption group. These effects are mainly among children age 25-59 months who, compared to younger children, are less likely to be breastfed and may be more directly affected by household diet changes associated with changes in agricultural practices and associated changes in crop production and/or incomes. These findings may be due to various benefits from adopting packages in the SI group – e.g., better access to nutritious legumes from use of maize-legume intercropping and synergistic effects between practices such as larger increases in crop yields when inorganic fertilizer is used jointly with organic fertilizer and/or maize-legume intercropping. Overall, the results suggest that the use of inorganic fertilizer together with maize-legume intercropping and/or organic fertilizer on maize plots can substantially enhance child nutrition in rural Tanzania.

Our results have two main implications for agricultural policy and future research. First, it is important for policy makers to find effective ways to increase joint use 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 first stage results (Table A1) suggest that agricultural extension and subsidies for inorganic fertilizer may be effective strategies to promote these practices; however, additional research is needed to confirm these findings and to identify cost-effective extension approaches and input subsidy designs to promote SI. Second, future research could examine if SI of maize production also enhances household food security and could identify the pathways through which SI of maize production affects child nutrition (and potentially household food security).

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APPENDIX

Table A1. CRE Mixed Multinomial Logit Estimates of the Determinants of Adoption of Each SI Category (Relative to the Non-Adoption Base Category)

Variables	Intensification	Sustainable	SI
Child Characteristics			
Child age (months)	-0.014**	0.004	0.002
	(0.006)	(0.004)	(0.007)
Child gender (1=male)	0.119	0.101	-0.094
	(0.231)	(0.105)	(0.204)
Diarrhea (1=yes)	-0.317	0.205	0.266
	(0.353)	(0.184)	(0.335)
Mother's education	0.010	-0.015	0.067
	(0.057)	(0.029)	(0.050)
Monthly difference	-0.020	-0.006	0.022
	(0.037)	(0.018)	(0.033)
T2 dummy	0.050	-0.125	0.011
	(0.243)	(0.123)	(0.240)
T3 dummy	0.654	-0.496	0.469
	(1.005)	(0.543)	(0.873)
Household Characteristics			
Head gender (1=male)	0.216	-0.144	0.053
	(0.523)	(0.212)	(0.373)
Head age (years)	-0.018	-0.011	-0.002
	(0.030)	(0.026)	(0.044)
Head education (years)	0.098	-0.023	0.063
	(0.061)	(0.026)	(0.042)
Spouse education (years)	-0.015	0.019	0.004
	(0.073)	(0.034)	(0.054)
Family labor	0.030	0.003	-0.019
	(0.148)	(0.124)	(0.161)
No. of female adults	-0.054	-0.150	-0.118
	(0.285)	(0.232)	(0.329)
No. of elderly	-0.320	0.053	-0.250
	(0.640)	(0.730)	(0.940)
No. of child	0.347**	-0.079	0.045
	(0.172)	(0.099)	(0.171)
No. of siblings	-1.361**	0.094	-1.918
	(0.554)	(0.486)	(2.036)
Head marital status (1=yes)	0.321	-0.028	0.174
	(0.342)	(0.170)	(0.302)
Off-farm income (1=yes)	0.045	0.643***	0.705*
	(0.440)	(0.239)	(0.376)
Access to safe drinking water source (1=yes)	0.671**	0.211	-0.424
	(0.294)	(0.173)	(0.285)
Safe drinking water (1=yes)	0.688**	0.107	0.295
	(0.300)	(0.169)	(0.281)
Sanitation (toilet) (1=yes)	1.058**	-0.016	1.194**
	(0.509)	(0.182)	(0.561)

Table A1. cont.

Variables	Intensification	Sustainable	SI
Agricultural Characteristics			
Total cultivated land (acres)	0.000	0.018	-0.065
	(0.047)	(0.019)	(0.050)
Own plot (1=yes)	-0.078	-0.142	1.136*
	(0.465)	(0.245)	(0.595)
Market distance (kms)	-0.021***	-0.006	-0.011
	(0.008)	(0.006)	(0.009)
Farm assets (1,000 TSh)	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)
Livestock (1=yes)	0.193	0.815***	0.805***
	(0.287)	(0.159)	(0.273)
Input and Output Prices			
Maize price (TSh/kg)	0.003**	-0.002**	-0.000
	(0.001)	(0.001)	(0.001)
Bean price (TSh/kg)	-0.000	-0.000	0.000
	(0.001)	(0.000)	(0.001)
Groundnut price (TSh/kg)	-0.000	-0.000	-0.001
	(0.000)	(0.000)	(0.000)
Inorganic fertilizer price (TSh/kg)	0.001	0.001**	0.001
	(0.001)	(0.000)	(0.001)
Community Characteristics			
Gov. health/hospital (1=yes)	0.437	0.087	-0.173
	(0.300)	(0.151)	(0.296)
Instrumental Variables			
Cooperatives (1=yes)	0.755***	-0.202	0.624***
	(0.287)	(0.153)	(0.240)
Extension from coop. (1=yes)	1.572***	0.101	2.467***
	(0.492)	(0.425)	(0.451)
Input subsidy voucher (1=yes)	4.503***	-0.270	3.653***
	(0.468)	(0.594)	(0.477)
Constant	-3.046**	-1.387**	-5.237***
	(1.275)	(0.667)	(1.287)

Notes: Sample size is 2,898 individuals (2,055 households) 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. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. Robust standard errors are in parentheses.

Table A2. Falsification Test Results (Parameter Estimates from CRE-Pooled OLS Regressions for Households in the Non-Adoption Category)

Variables	HAZ	WAZ
Child Characteristics		
Child age (months)	0.005	-0.005**
	(0.003)	(0.002)
Child gender (1=male)	-0.147*	-0.032
	(0.085)	(0.068)
Diarrhea (1=yes)	-0.106	-0.096
	(0.124)	(0.103)
Mother's education	-0.030	-0.028*
	(0.020)	(0.016)
Monthly difference	-0.006	0.022**
	(0.012)	(0.009)
T2 dummy	0.129	0.055
	(0.083)	(0.067)
T3 dummy	0.851***	0.301
	(0.289)	(0.377)
Household Characteristics		
Head gender (1=male)	-0.103	-0.049
	(0.139)	(0.113)
Head age (years)	-0.012	-0.022**
	(0.016)	(0.011)
Head education (years)	-0.012	0.004
	(0.017)	(0.014)
Spouse education (years)	0.022	0.024
	(0.023)	(0.019)
Family labor	0.025	0.000
	(0.064)	(0.030)
No. of female adults	0.041	-0.044
	(0.137)	(0.111)
No. of elderly	0.306	0.259
	(0.376)	(0.255)
No. of child	0.043	0.074
	(0.093)	(0.065)
No. of siblings	0.138	0.060
	(0.193)	(0.181)
Head marital status (1=yes)	0.096	0.050
	(0.114)	(0.090)
Off-farm income (1=yes)	-0.029	0.001
	(0.161)	(0.113)
Access to safe drinking water source (1=yes)	0.040 (0.109)	-0.031 (0.087)
Safe drinking water (1=yes)	0.090	0.021
	(0.096)	(0.075)
Sanitation (toilet) (1=yes)	0.049	0.012
	(0.101)	(0.078)

Table A2. cont.

Variables	HAZ	WAZ
Agricultural Characteristics		
Total cultivated land (acres)	-0.009	-0.004
	(0.012)	(0.013)
Own plot (1=yes)	-0.226	-0.080
	(0.142)	(0.129)
Market distance (kms)	-0.002	0.001
	(0.003)	(0.002)
Farm assets (1,000 TSh)	-0.000	0.000
	(0.000)	(0.000)
Livestock (1=yes)	0.085	0.101
	(0.098)	(0.078)
Input and Output Prices		
Maize price (TSh/kg)	-0.000	-0.000
	(0.000)	(0.000)
Bean price (TSh/kg)	0.000	0.000*
	(0.000)	(0.000)
Groundnut price (TSh/kg)	0.000	0.000
	(0.000)	(0.000)
Inorganic fertilizer price (TSh/kg)	-0.001*	-0.000
	(0.000)	(0.000)
Community Characteristics		
Gov. health/hospital (1=yes)	0.006	0.016
	(0.089)	(0.072)
Instrumental Variables		
Cooperatives (1=yes)	-0.060	-0.072
	(0.092)	(0.072)
Extension from coop. (1=yes)	0.143	0.198
	(0.245)	(0.192)
Input subsidy voucher (1=yes)	-0.385	-0.090
	(0.242)	(0.244)
Constant	-2.445***	-1.439***
	(0.421)	(0.336)

Notes: Sample size is 1,286 individuals in the Non-adoption category. Time-averages of household level variables to control for time-constant unobserved heterogeneity were included in the model but not reported in Table A2. ***, **, and * denote statistically significance at the 1%, 5%, and 10% levels, respectively. Standard errors are in parentheses.

Table A3. Second Stage Estimates for Child Nutritional Outcomes

Variables	Full-sample		Sub-sample 1		Sub-sample 2	
	HAZ	WAZ	HAZ	WAZ	HAZ	WAZ
Child characteristics						
Child age (months)	0.001	-0.006***	0.011**	-0.007**	0.013***	-0.011***
	(0.002)	(0.002)	(0.004)	(0.003)	(0.004)	(0.004)
Child gender (1=male)	-0.156***	-0.041	-0.156***	-0.014	-0.013	0.102*
	(0.056)	(0.047)	(0.060)	(0.048)	(0.068)	(0.056)
Diarrhea (1=yes)	-0.280***	-0.166**	-0.215**	-0.105	-0.180	-0.084
	(0.086)	(0.071)	(0.094)	(0.075)	(0.133)	(0.126)
Mother's education	-0.002	-0.011	-0.001	-0.012	-0.001	-0.021
	(0.014)	(0.012)	(0.015)	(0.012)	(0.016)	(0.014)
Monthly difference	-0.004	0.013**	0.009	0.021***	0.012	0.021***
	(0.008)	(0.006)	(0.009)	(0.007)	(0.010)	(0.008)
T2 dummy	0.031	0.008	0.093	-0.008	-0.240	-0.038
	(0.064)	(0.049)	(0.069)	(0.053)	(0.181)	(0.137)
T3 dummy	0.516**	0.472	1.263***	0.747		
	(0.236)	(0.297)	(0.279)	(0.459)		
Household characteristics						
Head gender (1=male)	0.088	0.038	0.123	0.036	0.038	-0.006
	(0.100)	(0.079)	(0.112)	(0.082)	(0.122)	(0.095)
Head age (years)	0.004	-0.002	-0.002	0.001	0.029	0.023
	(0.010)	(0.007)	(0.011)	(0.009)	(0.053)	(0.063)
Head education (years)	0.005	0.003	0.009	0.005	0.005	0.004
	(0.012)	(0.010)	(0.013)	(0.010)	(0.014)	(0.011)
Spouse education (years)	0.004	0.017	0.002	0.013	0.010	0.027*
	(0.017)	(0.013)	(0.018)	(0.013)	(0.019)	(0.015)
Family labor	0.021	-0.003	-0.031	-0.023	-0.250***	-0.383***
	(0.048)	(0.026)	(0.058)	(0.028)	(0.085)	(0.112)
No. of female adults	-0.045	-0.061	-0.014	-0.051	0.070	-0.383*
	(0.076)	(0.059)	(0.076)	(0.067)	(0.274)	(0.221)
No. of elderly	0.010	-0.044	-0.013	0.012	0.033	-0.368
	(0.309)	(0.196)	(0.301)	(0.214)	(0.313)	(0.394)
No. of child	-0.003	0.033	-0.044	0.013	-0.045	0.106
	(0.053)	(0.033)	(0.038)	(0.035)	(0.113)	(0.093)
No. of siblings	0.175	0.110	0.121	0.273**	-2.756***	-3.303***
	(0.149)	(0.111)	(0.149)	(0.111)	(0.771)	(1.031)
Head marital status (1=yes)	0.118	0.049	0.076	0.043	0.131	0.085
	(0.079)	(0.060)	(0.087)	(0.065)	(0.100)	(0.077)
Off-farm income (1=yes)	-0.080	-0.056	-0.099	-0.041	0.214	0.423**
	(0.109)	(0.091)	(0.115)	(0.086)	(0.202)	(0.182)
Access to safe drinking water source (1=yes)	0.074	-0.004	0.046	0.001	-0.065	-0.047
	(0.075)	(0.063)	(0.082)	(0.064)	(0.088)	(0.065)
Safe drinking water	0.034	0.013	0.077	0.036	0.054	0.087
	(0.066)	(0.055)	(0.072)	(0.059)	(0.077)	(0.065)
Sanitation (toilet) (1=yes)	-0.219***	-0.063	-0.216**	-0.097	-0.204**	-0.127
	(0.081)	(0.067)	(0.086)	(0.068)	(0.095)	(0.079)
Agricultural characteristics						
Total cultivated land (acres)	0.001	-0.001	-0.016*	-0.006	-0.003	0.012
	(0.005)	(0.005)	(0.009)	(0.007)	(0.022)	(0.024)
Own plot (1=yes)	-0.046	0.018	-0.026	0.043	-0.015	0.036
	(0.108)	(0.098)	(0.123)	(0.105)	(0.130)	(0.124)

Table A3. cont.

Variables	Full-sample		Sub-sample 1		Sub-sample 2	
	HAZ	WAZ	HAZ	HAZ	WAZ	HAZ
Market distance (kms)	-0.001	0.001	-0.000	0.001	0.003	0.003
	(0.002)	(0.002)	(0.002)	(0.002)	(0.003)	(0.002)
Farm assets (1,000 TZS)	-0.000	0.000	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Livestock (1=yes)	0.028	0.075	-0.023	0.041	0.004	-0.014
	(0.068)	(0.075)	(0.078)	(0.068)	(0.083)	(0.074)
Input and output prices						
Maize price (TZS/kg)	0.000	0.000	0.001**	0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Bean price (TZS/kg)	0.000	0.000	0.000	0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)
Groundnut price (TZS/kg)	0.000	-0.000	0.000**	0.000	0.001**	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Inorganic fertilizer price (TZS/kg)	-0.000	0.000	-0.000	0.000	0.001***	0.001**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Community characteristics						
Gov. health/hospital (1=yes)	-0.014	0.009	-0.024	0.011	0.035	0.023
	(0.062)	(0.051)	(0.068)	(0.053)	(0.074)	(0.060)
SI category						
Intensification	-0.535***	-0.038	-0.103	-0.110	-0.210	-0.207
	(0.155)	(0.309)	(0.192)	(0.223)	(0.199)	(0.198)
Sustainable	0.130	0.128	0.599***	0.148	-0.139	0.031
	(0.150)	(0.370)	(0.203)	(0.304)	(0.140)	(0.125)
SI	0.598***	0.426**	0.332**	0.607***	0.360*	0.576***
	(0.135)	(0.175)	(0.152)	(0.122)	(0.186)	(0.113)
Selection terms						
Intensification (λ_I)	0.751***	0.200	0.362**	0.238	0.395***	0.418*
	(0.130)	(0.335)	(0.143)	(0.191)	(0.152)	(0.231)
Sustainable (λ_S)	-0.076	-0.097	-0.759***	-0.153	0.126	-0.021
	(0.157)	(0.443)	(0.236)	(0.363)	(0.141)	(0.127)
SI (λ_{SI})	-0.783***	-0.487**	-0.449***	-0.801***	-0.640***	-0.743***
	(0.101)	(0.216)	(0.136)	(0.123)	(0.198)	(0.064)
Age dummy and Interaction terms						
6-24 months of age dummy			-0.043	-0.091		
			(0.113)	(0.088)		
Intensification×6-24 months of age			-0.139	-0.075		
			(0.228)	(0.173)		
Sustainable×6-24 months of age			0.188	0.030		
			(0.117)	(0.088)		
SI×6-24 months of age			0.112	0.073		
			(0.172)	(0.146)		
Constant	-2.720***	-1.540***	-3.393***	-1.638***	-3.340***	-1.395***
	(0.291)	(0.252)	(0.345)	(0.266)	(0.358)	(0.294)
Observations	2,898	2,898	2,560	2,560	1,453	1,453

Notes: 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 A3. Base category is Non-adoption. ***, **, and * denote statistically significance at the 1%, 5%, and 10% levels, respectively. Standard errors clustered at the household level are in parentheses.

Table A4. CRE METE model estimates for robustness checks

Variables	HAZ	WAZ
Full sample (n=2,549): children aged 0-59 months at the maize harvest		
Intensification	-0.177	-0.158
	(0.155)	(0.195)
Sustainable	0.751***	0.213
	(0.132)	(0.147)
SI	0.507***	0.552***
	(0.142)	(0.147)
Mother's age	0.010*	-0.001
	(0.005)	(0.004)
Mother's BMI	0.018*	0.051***
	(0.010)	(0.008)
Selection terms(λ)		
Intensification (λ_I)	0.308***	0.290
	(0.097)	(0.187)
Sustainable (λ_S)	-0.839***	-0.221
	(0.130)	(0.158)
SI (λ_{SI})	-0.621***	-0.725***
	(0.112)	(0.134)
Sub-sample 1 (n=2,221): children aged 6-59 months at the maize harvest		
Intensification	-0.432**	-0.185
	(0.213)	(0.234)
Sustainable	0.286	-0.008
	(0.357)	(0.289)
SI	0.355**	0.382***
	(0.180)	(0.141)
Intensification×6-24 months of age	-0.082	-0.136
	(0.246)	(0.180)
Sustainable×6-24 months of age	0.219*	0.018
	(0.124)	(0.093)
SI×6-24 months of age	0.114	0.071
	(0.180)	(0.149)
Mother's age	0.009*	-0.001
	(0.005)	(0.004)
Mother's BMI	0.026***	0.052***
	(0.010)	(0.008)

Notes: 500 simulation draws were used. Base category is Non-adoption. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. Standard errors clustered at the household level are in parentheses. The selection terms (λ) for the sub-sample analysis are excluded to conserve space. Sub-sample 2 with children aged 25-59 months at the maize harvest for robustness checks does not converge.

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