Received: 12 June 2018 | Revised: 15 May 2019 | Accepted: 8 July 2019

DOI: 10.1111/agec.12520

AGRICULTURAL ECONOMICS
The Journal of the International Association of Agricultural Economists
IAAE
WILEY

ORIGINAL ARTICLE

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

Jongwoo Kim[1] | **Nicole M. Mason**[1] | **Sieglinde Snapp**[2] | **Felicia Wu**[1,3]

[1]Department of Agricultural, Food, and Resource Economics, Michigan State University, East Lansing, Michigan

[2]Department of Plant, Soil, and Microbial Sciences, Michigan State University, East Lansing, Michigan

[3]Department of Food Science and Human Nutrition, Michigan State University, East Lansing, Michigan

Correspondence
Jongwoo Kim, Ph.D. student, Justin S. Morrill Hall of Agriculture, 446 West Circle Drive, Room 202, East Lansing, MI 48824-1039.
Email: kimjon36@msu.edu

Funding information
The U.S. Agency for International Development (USAID), Grant Numbers AID-OAA-L-14-00006 and AID-OAA-L-13-00001; U.S. Department of Agriculture (USDA) and Michigan AgBioResearch, Project Number MICL02501

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 agricultural management practices and inputs that contribute to SI from an environmental standpoint do indeed improve food security or child nutrition. We use three waves of data from the nationally-representative Tanzania National Panel Survey to analyze the child nutrition effects of rural households' adoption of farming practices that can contribute to the SI of maize production. We group households into four categories based on their use of three soil fertility management practices on their maize plots: "Nonadoption"; "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). The results from multinomial endogenous treatment effects models with the Mundlak–Chamberlain device suggest that use of practices in the "SI" category is associated with improvements in children's height-for-age and weight-for-age z-scores relative to "Nonadoption," particularly for children aged 25–59 months. These effects appear to come through improvements in both crop income and productivity.

KEYWORDS

Africa, child malnutrition, maize, multinomial endogenous treatment effects, sustainable intensification, Tanzania

JEL CLASSIFICATIONS

I15, O33, Q12, Q16

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, IFAD, and WFP, 2015; Godfray et al., 2010; Koppmair, Kassie, & Qaim, 2017). Hunger and child malnutrition are especially serious problems in sub-Saharan Africa (SSA). For example, in 2017, globally about 151 million children under age five were stunted and more than one-third of these children lived in Africa (UNICEF, WHO, and World Bank Group, 2018). Moreover, approximately 45% of global deaths of children under age five are linked to malnutrition and the mortality rate of children in SSA is the highest in the world (Black et al., 2013).

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

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

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

This study further contributes to the literature in several ways. First, to our knowledge, it is the first empirical investigation of how *combinations* of agricultural practices in general (as opposed to single technologies) and ISFM in particular affect child nutrition. Second, we explore whether these effects operate through the crop productivity and/or income pathways. Third, we use household-level panel data, whereas Manda et al. (2016a) and Zeng et al. (2017) use cross-sectional data. This enables us to control for time-constant unobserved heterogeneity, which should improve the internal validity of our estimates. And fourth, we contribute to the production diversity–dietary diversity/nutrition literature (see, for example, Hirvonen & Hoddinott, 2017; Jones et al., 2014; Kumar, Harris, & Rawat, 2015; Parvathi, 2018; Sibhatu et al., 2015) by studying whether production diversity (proxied in this study by maize–legume intercropping), intensification (proxied by inorganic fertilizer use on maize), or a combination of the two is most beneficial for child nutrition outcomes.[2]

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

[1] Several recent studies in *Agricultural Economics* have examined the determinants of adoption (and/or impacts on outcomes other than child nutrition) of some of these practices or other land management practices in SSA (e.g., Abdulai, 2016; Amare & Shiferaw, 2017; Manda, Alene, Gardebroek, Kassie, & Tembo, 2016b; Schmidt, Chinowsky, Robinson, & Strzepek, 2017; Wainaina, Tongruksawattana, & Qaim, 2016; Wossen, Berger, & Di Falco, 2015).

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

2 | SI OF MAIZE PRODUCTION IN TANZANIA

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

Inorganic fertilizer is a key input associated with conventional agricultural intensification and it has been a major reason for the dramatic increase in food production globally over the past 50 years (Crews & Peoples, 2005; Pingali, 2012). However, overuse of inorganic fertilizer can result in pollution of ground and surface water (Byrnes, 1990; Hart, Quin, & Nguyen, 2004), and chemical fertilizer application without the use of complementary soil building practices (e.g., maize–legume intercropping and organic fertilizer) may lead to a decrease in soil pH, soil organic carbon, soil aggregation, and microbial communities (Bronick & Lal, 2005).

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

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

Table 1 shows the prevalence of each of the eight possible combinations of the three SFM practices and each of the four SI categories on Tanzanian households' maize plots. Of 6,383 maize plots pooled across three rounds of survey data (the Tanzania National Panel Surveys [TNPS] of 2008/2009, 2010/2011, and 2012/2013, described below), 38% fall in the "Sustainable" category, 7% in "Intensification," 8% in "SI," and 47% in "Nonadoption." For the empirical approach used in this study and described below (a multinomial endogenous treatment effects [METE] model), we need to define a household-level SI category variable based on the plot-level SI category information. (This is because the METE model requires that the 'treatment' variable be a mutually exclusive categorical variable.) To do so, we calculate the total area of a household's maize plots in each SI category and then choose the SI category that has the largest area. The prevalence of these household-level SI categories is summarized in Table 1 and is very similar to the plot-level results. This is because 64% of households in the sample have only one maize plot, and those with multiple maize plots tend to use the same SFM practices on all maize plots. Overall, 87% of the maize plots in the sample have the same SI category at the plot- and household-level.[4]

3 | CONCEPTUAL AND ECONOMETRIC FRAMEWORK

3.1 | Conceptual framework

Tanzania is the third worst affected country in SSA based on the prevalence of stunting (UNICEF, 2009). As of 2012/2013, 37.4% of children under age five were stunted (i.e., HAZ < -2) and 12.5% were underweight (i.e., WAZ < -2), with the prevalence of malnutrition markedly higher in rural than in urban areas (TNBS, 2014).[5] HAZ

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

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

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

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	Nonadoption	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

Notes. Figures in the plot level column are based on all maize plots ($N = 6{,}383$) cultivated by rural households pooled across the three waves of the TNPS (2008/2009, 2010/2011, and 2012/2013). Figures in the HH level column are based on the total number of maize growers ($N = 4{,}269$) in rural areas across these surveys. Legume crops for maize–legume intercropping are beans, soybeans, groundnuts, cowpeas, pigeon peas, chickpeas, field peas, green grams, bambara nuts, and fiwi.

and WAZ reflect long-term factors such as deficiencies in nutrition, frequent infections, and inappropriate feeding practices (Alderman, Hoogeveen, & Rossi, 2005; TNBS, 2014).

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

3.2 | METE model

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

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

AGRICULTURAL ECONOMICS The Journal of the International Association of Agricultural Economists IAAE

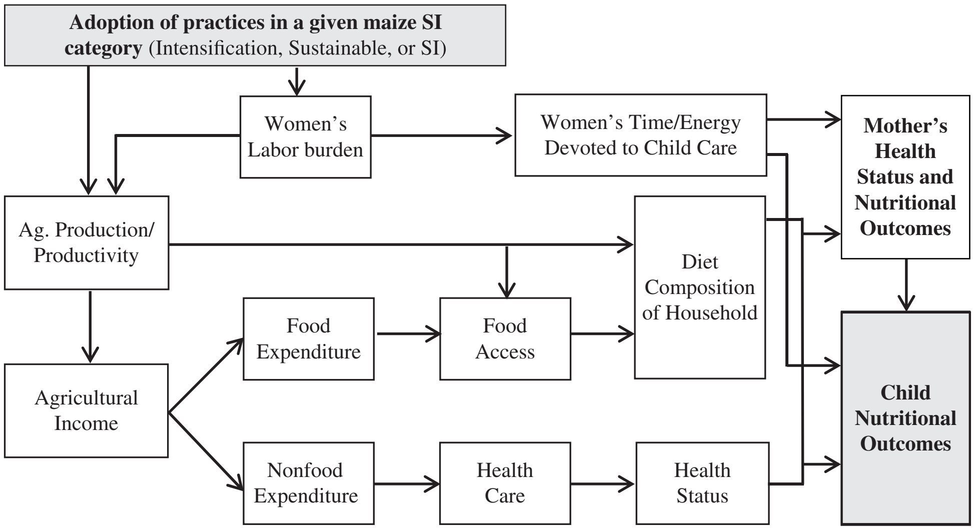

FIGURE 1 Conceptual pathways between SI of maize production and child nutrition
Source. Adapted from Herforth and Harris (2014).

(Wooldridge, 2010). As a benchmark to the CRE-METE models, we also report household fixed effects (FE) and CRE-pooled ordinary least squares (POLS) results for the main model below.[6]

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

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

Without loss of generality, let $j = 0$ denote the control group ("Nonadoption") and $EV_{ij}^* = 0$.

$\mathbf{z}_i$ is a vector of exogenous covariates (described below) with associated parameters $\boldsymbol{\alpha}_j$; η_{ij} are independently and identically distributed error terms; and l_{ij} is unobserved characteristics common to household i's adoption of the jth alternative and the outcome variables (HAZ and WAZ).

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

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

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

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

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

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

where $y_{i,n}$ is the nutrition outcome of interest for child n in household i. $\mathbf{x}_i$ is a vector of exogenous covariates including two subvectors: household i's characteristics $\mathbf{h}_i$ and child n's characteristics $\mathbf{c}_{i,n}$. The associated parameter vector is $\boldsymbol{\beta}$. Parameters γ_j (for $j = 1, 2, 3$) denote the treatment effects relative to the control group ("Nonadoption"). $E(y_{i,n} | \mathbf{d}_i, \mathbf{x}_i, \mathbf{l}_i)$ is a function of each of the latent factors l_{ij}; that is, the outcome variable may be influenced by unobserved characteristics that also affect selection into treatment. If λ_j is positive (negative), treatment and outcome are positively (negatively) associated with unobserved variables—that is, there is positive (negative) selection. We assume that the outcome variables (z-scores) follow a normal distribution. The model is estimated using a maximum simulated

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

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

likelihood approach and 700 Halton sequence-based quasi-random draws.[8]

In principle, the parameters of the semistructural model are identified through nonlinear functional forms; however, including some variables in $\boldsymbol{z}_i$ that do not enter in $\boldsymbol{x}_i$ is the preferred approach for more robust identification (Deb & Trivedi, 2006a, 2006b). We therefore include the following as excluded instrumental variables (IVs): the proportion of *other* households in the household's ward (excluding the household itself) that (a) received agricultural production advice, (b) that used inorganic fertilizer, and (c) that used maize–legume intercropping; (d) electoral threat at the district level; and (e) the number of the National Agricultural Input Voucher Scheme (NAIVS) subsidized fertilizer vouchers allocated to the household's region.[9] The first three IVs are related to access to information on and the potential for social learning about SFM practices.[10] We expect these variables to be positively correlated with household i's adoption of SFM practices but not to directly affect the household's child nutrition outcomes. Regarding IVs (d) and (e), a household's SI category decision could be affected by its receipt of subsidized fertilizer vouchers; however, this is likely to be endogenous, so we instead use (d) and (e) because these are likely to affect the household's receipt of such vouchers but are exogenous to an individual household. Electoral threat, as defined by Chang (2005), is the proportion of votes for the runner-up divided by the proportion of votes for the presidential winner. Previous studies indicate that the spatial allocation of subsidized inputs in some SSA countries, including Tanzania, may be linked to voting patterns during the most recent election (see, among others, Mason, Jayne, and Van De Walle (2017) for Zambia; Mather and Minde (2016) for Tanzania; and Mather and Jayne (2018) for Kenya). We therefore use Mather and Minde's electoral threat variable, which is based on data from the 2005 and 2010 Tanzania presidential elections.[11] Subsidized fertilizer vouchers for maize in Tanzania are also targeted based on the suitability of different areas for maize production.[12] We therefore include as another IV the number of vouchers allocated to the household's region per the World Bank (2014).

Although there is no formal test for the validity of exclusion restrictions in a nonlinear setting (Deb & Trivedi, 2006a), we follow Di Falco, Veronesi, and Yesuf (2011) and perform a simple falsification test where these candidate IVs are included as additional explanatory variables along with $\boldsymbol{z}_i$ in a CRE-POLS regression, whereas the dependent variable is the HAZ or WAZ of children in households in the "Nonadoption" group. If the candidate IVs are not statistically significant in this regression, this lends support to the validity of the exclusion restrictions. All IVs used here pass this simple falsification test (see Table A1 in the online appendix); however, we acknowledge that this is not ironclad evidence that the exclusion restrictions are valid. A useful extension of this study would be a randomized controlled trial that generates exogenous variation in the adoption of the SI categories (e.g., through different information treatments) and measures the effects on child nutrition.

4 | DATA

With the exception of IVs (d) and (e) above, the data come from the TNPS, which is a nationally-representative household survey that contains detailed information on socioeconomic characteristics, consumption, agricultural production, and nonfarm income generating activities, inter alia. The TNPS is a four-wave panel survey conducted in 2008/2009, 2010/2011, 2012/2013, and 2014/2015 but only the data from the first three waves are used here because the sample in the fourth wave was refreshed for future rounds. The TNPS is based on a stratified, multistage cluster sample design and the clusters within each stratum are randomly selected as the primary sampling units, where there are four different strata: Dar es Salaam, other urban areas on mainland Tanzania, rural mainland Tanzania, and Zanzibar. The TNPS baseline (2008/2009) sample of 3,265 households is clustered in 409 enumeration areas. These households and their members were tracked and reinterviewed in the second (TNPS 2010/2011) and third waves (TNPS 2012/2013) with very low attrition rates between waves (TNBS, 2014).

We start with observations of children under age five (0–59 months) in rural households that grew maize in the main farming season (i.e., the long-rainy season) in a given wave but drop children age 0–5 months because they are typically exclusively breastfed during that period (Tanzania Food and Nutrition Centre, 2014) and thus less likely to be directly affected by diet changes associated with their household's SI adoption decisions. There are 1,871 total household observations meeting these criteria across the three waves of the TNPS (532 observations in 2008/2009, 560 in 2010/2011, and 779 in 2012/2013). These households contain a total of 2,486 children age 6–59 months (693 observations in 2008/2009, 727 in 2010/2011, and 1,066 in 2012/2013).

As per Table A2, among children in our sample, the mean values of HAZ and WAZ are −1.82 and −0.98, respectively;

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

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

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

[11] The authors thank Dr. David Mather for sharing these data.

[12] Recall that we are controlling for time-invariant heterogeneity, including suitability for maize production, via CRE.

47% are stunted and 15% are underweight. (This table and Table A3 also show descriptive statistics by SI category.) Anthropometric data to calculate nutritional status were collected from children an average (and median) of 10 months after the household began harvesting the maize (and this timing is controlled for in the econometric models). This implies that most children's WAZ and HAZ in our sample are mainly influenced by the household's SFM adoption decisions captured in the data and not by such decisions in the following year.

Tables A2 and A3 further provide summary statistics for the control variables used in the analysis. These variables were selected based on careful reviews of the technology adoption and child nutrition literatures and include child-level variables (age and gender, whether or not the child had diarrhea in the past 2 weeks, mother's education, monthly difference between maize harvest and collection of anthropometric data, and dummy variables for number of times the child appears across survey rounds); household characteristics (age and gender of the household head, education level of the household head and spouse, family labor [as defined in Table A3], number of female adults/elderly/children/siblings in the household, marital status of the household head, off-farm income, access to a safe drinking water source, use of safe drinking water, basic sanitation [toilet]); agricultural characteristics (total cultivated land; maize plot, farm equipment, and livestock ownership; distance to the nearest market); input and output prices; and community characteristics (whether or not a government health center/hospital is available within the community).

A child's biological parents' height and weight could also affect his/her nutritional status. However, such data on the child's biological father (mother) are missing for approximately 36% (15%) of the observations in our sample because the individual is no longer a household member or was otherwise not present when measurements were taken. Many models fail to converge with these reductions in sample size; however, we do report, as a robustness check, estimates that control for the mother's body mass index (BMI) (and age).[13] An important caveat is that BMI could be affected by if the woman is pregnant or not, but the TNPS data do not capture information on current pregnancy; thus there is likely to be measurement error in the BMI variable for at least some observations. Our inability to fully control for these biological parent characteristics is a limitation of this study. However, note that if height (of adults) is reasonably assumed to be constant over the survey waves, then our use of CRE indirectly controls for the parents' height.

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

TABLE 2 FE, CRE-POLS, and CRE-METE estimates: Impacts on nutritional outcomes of children aged 6–59 months (full sample)

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

Notes. $N = 2{,}486$. Base category is "Nonadoption." ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. Standard errors clustered at the household level in parentheses.

5 | RESULTS

Table 2 presents the CRE-METE estimates of the local average treatment effects of the various SI categories on children's HAZ and WAZ for the full sample of children aged 6–59 months. See Tables A4 and A5 for the full first- and second-stage results for this model. (Also note in Table A4 that two of the IVs associated with an increased probability of adoption of practices in the SI category by a given household are increases in the proportion of *other* households in the household's ward that use inorganic fertilizer or that practice maize–legume intercropping. We return to this point in the final section of the paper on policy implications.) For comparison purposes, we also report FE and CRE-POLS results that are estimated under the assumption that a household's SI category decision is exogenous after controlling for the observed

TABLE 3 CRE-METE estimates: Impacts on child nutritional outcomes with subsample analysis

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

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

covariates and time-invariant heterogeneity. The results of both the FE and CRE-POLS models suggest that there are no statistically significant nutritional effects for any of the SI treatment groups. However, we reject the null hypothesis of joint exogeneity of the SI category variables in all CRE-METE models estimated here, which suggests that endogeneity is indeed an issue.[14] In subsequent parts of this section, we therefore focus on the CRE-METE results, which correct for self-selection.

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

In addition to estimating the CRE-METE models for the full sample of children aged 6–59 months, we also estimate models for: (a) children aged 6–59 months with interaction terms between the SI treatment groups and an indicator variable for children aged 6–24 months; and (b) children aged 25–59 months only. The major rationale behind these additional analyses is that the growth faltering patterns of children under age five differ across ages (see Figure A1 in the online appendix). Victora, De Onis, Hallal, Blössner, and Shrimpton (2010) find that rapid growth faltering of HAZ was observed until 24 months of age, then plateauing from 25–59 months, while WAZ showed progressive and slow faltering through months 0–59, with the most rapid declines from 0 to 24 months. As a result, the child nutritional impacts of SI adoption decisions may also vary. In particular, the inclusion of the 6–24 months interaction terms allows us to test for differential effects of the SI treatment groups on the nutritional outcomes of children who are in the "critical window of opportunity" for the promotion of optimal growth, health, and development, which is the 1,000 days from conception through the first 2 years of life.[16]

[14] This test, following Deb and Trivedi (2006b), is a likelihood-ratio test where the null hypothesis is that the λs (selection terms) are jointly equal to zero (exogeneity of treatment). We reject the null in all cases ($p < .01$), which suggests that treatment is endogenous. To conserve space, we do not report the estimated λs in subsequent tables.

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

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

TABLE 4 CRE-METE estimates: Impacts on crop income and productivity

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

Notes. $N = 1{,}871$. Base category is "Nonadoption." ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. Standard errors clustered at the household level in parentheses.

In Table 3, the results including the interaction terms are presented in the upper panel and the results for children aged 25–59 months only are in the bottom panel. Together these results suggest that the positive effects of the "SI" category occur mainly among children aged 25–59 months. We continue to find no evidence of statistically significant effects for the "Sustainable" category. The negative effects of the "Intensification" category on HAZ are not robust to the model specification, as they cease to be statistically significant when we limit the sample to children aged 25–59 months. The lack of statistically significant effects of any SI categories on the HAZ and WAZ of children aged 6–24 months may be because these children are still being breastfed and largely dependent on complementary/weaning foods instead of consuming adult foods (Stephenson et al., 2017; Tanzania Food and Nutrition Centre, 2014; Zeng et al., 2017). Consistent with our findings, a recent study (Jain, 2018) finds that nutrient intake has no association with the HAZ of children aged 6–23 months in rural Bangladesh.

Table A6 shows the results for models that include the mother's BMI and age. These results suggest that the mother's BMI is positively correlated both child nutrition outcomes. Moreover, we still find that "SI" is positively correlated with both HAZ and WAZ.[17]

Overall, the robust finding across model specifications is that "SI" substantially enhances both HAZ and WAZ. This could be for the following reasons. First, note that 79% of the "SI" maize plots in Tanzania involve maize–legume intercropping (Table 1) and based on the results in Table A7, which exclude organic fertilizer, the combined use of maize–legume intercropping and inorganic fertilizer is a key driver of the positive "SI" effects on child nutrition.[18] The legume crops produced as a result may directly affect the diet composition of adopting households by providing needed protein and micronutrients (Messina, 1999); this, in turn, may positively affect child nutrition. Indeed, as shown in Table A8, 90% of sample households in the "SI" group produce legumes, whereas only 19% and 31% of households in the "Nonadoption" and "Intensification" groups, respectively, produce legumes.[19] The table also indicates that maize–legume intercropping is the dominant way in which maize-growing households in Tanzania produce legumes. In addition, Stahley, Slakie, Derksen-Schrock, Gugerty, and Anderson (2012) report that the mean quantity of legumes consumed by producing households in Tanzania is double that consumed by purchasing households. Furthermore, these legume crops could help farmers to increase their crop income since per-kilogram prices for legumes are higher than maize prices (see Table A3). Second, relative to farmers in the other treatment groups, households in the "SI" treatment group may have higher crop productivity or incomes due to synergistic effects when "Sustainable" practices are used jointly with inorganic fertilizer. Indeed, a review by Place et al. (2003) indicates that there is considerable evidence demonstrating positive effects on overall yields and net financial returns of combined use of inorganic fertilizer and organic soil fertility practices including animal manure and intercropping with legumes.

To explore if the "SI" effects come through the crop income and/or productivity pathways, we estimate CRE-METE models for two additional outcome variables: (a) gross value of crop production from the household's maize plots as a proxy for crop income; and (b) an index of crop output per acre on those plots as a proxy for productivity.[20] The associated CRE-METE results are shown in Table 4 and suggest that "SI" is indeed associated with increases in crop income and productivity on households' maize plots. "Intensification" is as well but the crop income effects are considerably and statistically larger for "SI." In contrast, "Sustainable" is associated with negative effects on crop income and no significant effects on productivity.

[17] Table A6 also suggests that "Intensification" is negatively associated with HAZ and WAZ for children aged 6–59 months. However, we could not confirm that this holds for children aged 25–59 months because the model does not converge.

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

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

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

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

6 | CONCLUSIONS AND IMPLICATIONS

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

Our results have two main implications for agricultural policy and future research. First, given the potential benefits of joint use of inorganic fertilizer with maize–legume intercropping (and possibly organic fertilizer) for soil fertility, crop income, productivity, and child nutrition outcomes, it is important for policy makers to identify ways to promote use of such practices by Tanzanian maize farmers. (At present, Tanzania has much lower adoption rates of these practices than other countries in eastern and southern Africa such as Kenya, Malawi, and Ethiopia (Kassie, Teklewold, Jaleta, Marenya, & Erenstein, 2015a).) Further research is needed to identify cost-effective SI promotion strategies and our results do not speak directly to this question in a major way. However, based on our results, one general approach that may warrant further investigation (among others) is leveraging social learning to encourage SI of maize production. (Recall that the first-stage results in Table A4 suggest that increases in the proportion of other households in a household’s ward using inorganic fertilizer and maize–legume intercropping are associated with an increased probability of adoption of practices in the “SI” category by the household itself.) A second area in need of further research is if and how SI of agricultural systems more broadly (i.e., beyond maize) contributes to food security and child nutrition outcomes.

ACKNOWLEDGMENTS

This study is made possible by the generous support of the American People provided to the Feed the Future (FtF) Innovation Lab for Sustainable Intensification [grant number AID-OAA-L-14-00006] and the Feed the Future Innovation Lab for Food Security Policy [grant number AID-OAA-L-13-00001] through the United States Agency for International Development (USAID). This work was also supported by the U.S. Department of Agriculture (USDA) National Institute of Food and Agriculture and Michigan AgBioResearch [project number MICL02501]. The contents were the sole responsibility of the authors and do not necessarily reflect the views of USAID, USDA, the U.S. Government, or Michigan AgBioResearch.

REFERENCES

Abdulai, A. N. (2016). Impact of conservation agriculture technology on household welfare in Zambia. *Agricultural Economics*, *47*(6), 729–741. https://doi.org/10.1111/agec.12269

Agboola, A. A., & Fayemi, A. A. (1971). Preliminary trials on the intercropping of maize with different tropical legumes in Western Nigeria. *Journal of Agricultural Science*, *77*(2), 219–225. https://doi.org/10.1017/S0021859600024345

Alderman, H., Hoogeveen, H., & Rossi, M. (2005). Reducing child malnutrition in Tanzania-combined effects of income growth and program interventions. *Economics and Human Biology*, *4*(1), 1–23.

Amare, M., & Shiferaw, B. (2017). Nonfarm employment, agricultural intensification, and productivity change: Empirical findings from Uganda. *Agricultural Economics*, *48*(S1), 59–72. https://doi.org/10.1111/agec.12386

Black, R. E., Victora, C. G., Walker, S. P., Bhutta, Z. A., Christian, P., De Onis, M., … Uauy, R. (2013). Maternal and child undernutrition and overweight in low-income and middle-income countries. *Lancet*, *382*(9890), 427–451. https://doi.org/10.1016/S0140-6736(13)60937-X

Bronick, C. J., & Lal, R. (2005). Soil structure and management: A review. *Geoderma*, *124*(1–2), 3–22. https://doi.org/10.1016/j.geoderma.2004.03.005

Byrnes, B. H. (1990). Environmental effects of N fertilizer use—An overview. *Fertilizer Research*, *26*(1–3), 209–215. https://doi.org/10.1007/BF01048758

Chang, E. C. (2005). Electoral incentives for political corruption under open-list proportional representation. *Journal of Politics*, *67*(3), 716–730. https://doi.org/10.1111/j.1468-2508.2005.00336.x

Chen, J. H. (2006, October). The combined use of chemical and organic fertilizers and/or biofertilizer for crop growth and soil fertility. In *International Workshop on Sustained Management of the Soil-Rhizosphere System for Efficient Crop Production and Fertilizer Use*. Thailand: Land Development Department Bangkok.

Crews, T. E., & Peoples, M. B. (2005). Can the synchrony of nitrogen supply and crop demand be improved in legume and fertilizer-based agroecosystems? A review. *Nutrient Cycling in Agroecosystems*, *72*(2), 101–120. https://doi.org/10.1007/s10705-004-6480-1

Deb, P., & Trivedi, P. K. (2006a). Specification and simulated likelihood estimation of a non-normal treatment-outcome model with selection: Application to health care utilization. *Econometrics Journal*, *9*(2), 307–331. https://doi.org/10.1111/j.1368-423X.2006.00187.x

Deb, P., & Trivedi, P. K. (2006b). Maximum simulated likelihood estimation of a negative binomial regression model with multinomial endogenous treatment. *Stata Journal*, *6*(2), 246–255. https://doi.org/10.1177%2F1536867X0600600206

Di Falco, S., & Veronesi, M. (2013). How can African agriculture adapt to climate change? A counterfactual analysis from Ethiopia. *Land Economics*, *89*(4), 743–766. https://doi.org/10.3368/le.89.4.743

Di Falco, S., Veronesi, M., & Yesuf, M. (2011). Does adaptation to climate change provide food security? A micro-perspective from Ethiopia. *American Journal of Agricultural Economics*, *93*(3), 829–846. https://doi.org/10.1093/ajae/aar006

Droppelmann, K. J., Snapp, S. S., & Waddington, S. R. (2017). Sustainable intensification options for smallholder maize-based farming systems in sub-Saharan Africa. *Food Security*, *9*(1), 133–150. https://doi.org/10.1007/s12571-016-0636-0

FAO, IFAD, and WFP. (2015). *The state of food insecurity in the world 2015. Meeting the 2015 international hunger targets: Taking stock of uneven progress*. Rome: FAO.

Godfray, H. C. J., Beddington, J. R., Crute, I. R., Haddad, L., Lawrence, D., Muir, J. F., … Toulmin, C. (2010). Food security: The challenge of feeding 9 billion people. *Science*, *327*(5967), 812–818. https://doi.org/10.1126/science.1185383

Hart, M. R., Quin, B. F., & Nguyen, M. (2004). Phosphorus runoff from agricultural land and direct fertilizer effects. *Journal of Environmental Quality*, *33*(6), 1954–1972. https://doi.org/10.2134/jeq2004.1954

Hawkes, C., & Ruel, M. T. (2006). *Understanding the links between agriculture and health (2020 Vision Focus 13)*. Washington, DC: International Food Policy Research Institute, (IFPRI).

Headey, D., Stifel, D., You, L., & Guo, Z. (2018). Remoteness, urbanization, and child nutrition in sub-Saharan Africa. *Agricultural Economics*, *49*(6), 765–775. https://doi.org/10.1111/agec.12458

Herforth, A., & Harris, J. (2014). *Understanding and applying primary pathways and principles*. Brief# 1. Improving Nutrition through Agriculture Technical Brief Series. Arlington, VA: USAID/Strengthening Partnerships, Results, and Innovations in Nutrition Globally (SPRING) Project.

Hirvonen, K., & Hoddinott, J. (2017). Agricultural production and children's diets: Evidence from rural Ethiopia. *Agricultural Economics*, *48*(4), 469–480. https://doi.org/10.1111/agec.12348

Jain, M. (2018). Large decrease in child stunting despite limited improvement in children's food intake: Evidence from rural Bangladesh. *Economic Development and Cultural Change*, *66*(3), 555–583. https://doi.org/10.1086/696532

Jayne, T. S., Mason, N. M., Burke, W. J., & Ariga, J. (2018). Taking stock of Africa's second-generation agricultural input subsidy programs. *Food Policy*, *75*, 1–14. https://doi.org/10.1016/j.foodpol.2018.01.003

Jones, A. D., Shrinivas, A., & Bezner-Kerr, R. (2014). Farm production diversity is associated with greater household dietary diversity in Malawi: Findings from nationally representative data. *Food Policy*, *46*, 1–12. https://doi.org/10.1016/j.foodpol.2014.02.001

Kassie, M., Jaleta, M., Shiferaw, B., Mmbando, F., & Mekuria, M. (2013). Adoption of interrelated sustainable agricultural practices in smallholder systems: Evidence from rural Tanzania. *Technological Forecasting and Social Change*, *80*(3), 525–540. https://doi.org/10.1016/j.techfore.2012.08.007

Kassie, M., Teklewold, H., Jaleta, M., Marenya, P., & Erenstein, O. (2015a). Understanding the adoption of a portfolio of sustainable intensification practices in eastern and southern Africa. *Land Use Policy*, *42*, 400–411. https://doi.org/10.1016/j.landusepol.2014.08.016

Kassie, M., Teklewold, H., Marenya, P., Jaleta, M., & Erenstein, O. (2015b). Production risks and food security under alternative technology choices in Malawi: Application of a multinomial endogenous switching regression. *Journal of Agricultural Economics*, *66*(3), 640–659. https://doi.org/10.1111/1477-9552.12099

Koppmair, S., Kassie, M., & Qaim, M. (2017). Farm production, market access and dietary diversity in Malawi. *Public Health Nutrition*, *20*(2), 325–335. https://doi.org/10.1017/S1368980016002135

Kumar, N., Harris, J., & Rawat, R. (2015). If they grow it, will they eat and grow? Evidence from Zambia on agricultural diversity and child undernutrition. *Journal of Development Studies*, *51*(8), 1060–1077. https://doi.org/10.1080/00220388.2015.1018901

Liu, Y., & Myers, R. (2009). Model selection in stochastic frontier analysis with an application to maize production in Kenya. *Journal of Productivity Analysis*, *31*(1), 33–46. https://doi.org/10.1007/s11123-008-0111-9

Loos, J., Abson, D. J., Chappell, M. J., Hanspach, J., Mikulcak, F., Tichit, M., & Fischer, J. (2014). Putting meaning back into "sustainable intensification". *Frontiers in Ecology and the Environment*, *12*(6), 356–361. https://doi.org/10.1890/130157

Manda, J., Gardebroek, C., Khonje, M. G., Alene, A. D., Mutenje, M., & Kassie, M. (2016a). Determinants of child nutritional status in the eastern province of Zambia: The role of improved maize varieties. *Food Security*, *8*(1), 239–253. https://doi.org/10.1007/s12571-015-0541-y

Manda, J., Alene, A. D., Gardebroek, C., Kassie, M., & Tembo, G. (2016b). Adoption and impacts of sustainable agricultural practices on maize yields and incomes: Evidence from rural Zambia. *Journal of Agricultural Economics*, *67*(1), 130–153. https://doi.org/10.1111/1477-9552.12127

Mason, N. M., Jayne, T. S., & Van De Walle, N. (2017). The political economy of fertilizer subsidy programs in Africa: Evidence from Zambia. *American Journal of Agricultural Economics*, *99*(3), 705–731. https://doi.org/10.1093/ajae/aaw090

Mather, D. L., & Jayne, T. S. (2018). Fertilizer subsidies and the role of targeting in crowding out: Evidence from Kenya. *Food Security*, *10*(2), 397–417. https://doi.org/10.1007/s12571-018-0773-8

Mather, D., & Minde, I. (2016). *Fertilizer subsidies and how targeting conditions crowding in/out: An assessment of smallholder fertilizer demand in Tanzania*. GISAIA Working Paper #5.

Messina, M. J. (1999). Legumes and soybeans: Overview of their nutritional profiles and health effects. *American Journal of Clinical Nutrition*, *70*(3), 439–450. https://doi.org/10.1093/ajcn/70.3.439s

Montpellier Panel. (2013). Sustainable intensification: A new paradigm for African agriculture. London.

Mpeketula, P. M., & Snapp, S. S. (2018). Structural stability conditions soil carbon gains from compost management and rotational diversity. *Soil Science Society of America Journal*, *83*, 203–211. https://doi.org/10.2136/sssaj2017.03.0076

Musumba, M., Grabowski, P., Palm, C., & Snapp, S. S. (2017). *Guide for the sustainable intensification assessment framework*. Manhattan, KS: Kansas State University.

Ollenburger, M., & Snapp, S. (2014). Model applications for sustainable intensification of maize-based smallholder cropping in a changing world. In L. R. Ahuja, L. Ma, & R. J. Lascano (Eds.), *Practical applications of agricultural system models to optimize the use of limited water* (pp. 375–398). American Society of Agronomy, Crop Science Society of America, Soil Science Society of America.

Petersen, B., & Snapp, S. (2015). What is sustainable intensification? Views from experts. *Land Use Policy*, *46*, 1–10. https://doi.org/10.1016/j.landusepol.2015.02.002

Pingali, P. L. (2012). Green revolution: Impacts, limits, and the path ahead. *Proceedings of the National Academy of Sciences*, *109*(31), 12302–12308. https://doi.org/10.1073/pnas.0912953109

Pinstrup-Andersen, P. (2007). Agricultural research and policy for better health and nutrition in developing countries: A food systems approach. *Agricultural Economics*, *37*, 187–198. https://doi.org/10.1111/j.1574-0862.2007.00244.x

Place, F., Barrett, C. B., Freeman, H. A., Ramisch, J. J., & Vanlauwe, B. (2003). Prospects for integrated soil fertility management using organic and inorganic inputs: Evidence from smallholder African agricultural systems. *Food Policy*, *28*(4), 365–378. https://doi.org/10.1016/j.foodpol.2003.08.009

Parvathi, P. (2018). Does mixed crop-livestock farming lead to less diversified diets among smallholders? Evidence from Laos. *Agricultural Economics*, *49*(4), 497–509. https://doi.org/10.1111/agec.12431

Rusinamhodzi, L., Corbeels, M., Nyamangara, J., & Giller, K. E. (2012). Maize–grain legume intercropping is an attractive option for ecological intensification that reduces climatic risk for smallholder farmers in central Mozambique. *Field Crops Research*, *136*, 12–22. https://doi.org/10.1016/j.fcr.2012.07.014

Schmidt, E., Chinowsky, P., Robinson, S., & Strzepek, K. (2017). Determinants and impact of sustainable land management (SLM) investments: A systems evaluation in the Blue Nile Basin, Ethiopia. *Agricultural Economics*, *48*(5), 613–627. https://doi.org/10.1111/agec.12361

Sibhatu, K. T., Krishna, V. V., & Qaim, M. (2015). Production diversity and dietary diversity in smallholder farm households. *Proceedings of the National Academy of Sciences*, *112*(34), 10657–10662. https://doi.org/10.1073/pnas.1510982112

Snapp, S. S., Blackie, M. J., Gilbert, R. A., Bezner-Kerr, R., & Kanyama-Phiri, G. Y. (2010). Biodiversity can support a greener revolution in Africa. *Proceedings of the National Academy of Sciences*, *107*(48), 20840–20845. https://doi.org/10.1073/pnas.1007199107

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

Stephenson, K. B., Agapova, S. E., Divala, O., Kaimila, Y., Maleta, K. M., Thakwalakwa, C., … Manary, M. J. (2017). Complementary feeding with cowpea reduces growth faltering in rural Malawian infants: A blind, randomized controlled clinical trial. *American Journal of Clinical Nutrition*, *106*(6), 1500–1507. https://doi.org/10.3945/ajcn.117.160986

Tanzania Food and Nutrition Centre. (2014). *Tanzania National Nutrition Survey 2014*.

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

Tilman, D., Cassman, K. G., Matson, P. A., Naylor, R., & Polasky, S. (2002). Agricultural sustainability and intensive production practices. *Nature*, *418*(6898), 671–677. https://doi.org/10.1038/nature01014

Tully, K., Sullivan, C., Weil, R., & Sanchez, P. (2015). The state of soil degradation in sub-Saharan Africa: Baselines, trajectories, and solutions. *Sustainability*, *7*(6), 6523–6552. https://doi.org/10.3390/su7066523

UNICEF. (2009). *Tracking progress on child and maternal nutrition: A survival and development priority*.

UNICEF, WHO, and World Bank Group. (2018). *Levels and trends in child malnutrition—Joint child malnutrition estimates*, 2018 edition.

Victora, C. G., De Onis, M., Hallal, P. C., Blössner, M., & Shrimpton, R. (2010). Worldwide timing of growth faltering: Revisiting implications for interventions. *Pediatrics*, *125*(3), e473–e480. https://doi.org/10.1542/peds.2009-1519

Waddington, S. R., Mekuria, M., Siziba, S., & Karigwindi, J. (2007). Long-term yield sustainability and financial returns from grain legume–maize intercrops on a sandy soil in subhumid north central Zimbabwe. *Experimental Agriculture*, *43*(4), 489–503. https://doi.org/10.1017/S0014479707005303

Wainaina, P., Tongruksawattana, S., & Qaim, M. (2016). Tradeoffs and complementarities in the adoption of improved seeds, fertilizer, and natural resource management technologies in Kenya. *Agricultural Economics*, *47*(3), 351–362. https://doi.org/10.1111/agec.12235

Woodfine, A. (2009). *Using sustainable land management practices to adapt to and mitigate climate change in sub-Saharan Africa. Resource Guide Version 1*. TerrAfrica.

Wooldridge, J. M. (2010). *Econometric analysis of cross section and panel data*. Cambridge, MA: MIT press.

Wossen, T., Berger, T., & Di Falco, S. (2015). Social capital, risk preference and adoption of improved farm land management practices in Ethiopia. *Agricultural Economics*, *46*(1), 81–97. https://doi.org/10.1111/agec.12142

World Bank (2014). *Tanzania public expenditure review: National agricultural input voucher scheme*. Washington, DC: World Bank.

Wu, J., & Babcock, B. A. (1998). The choice of tillage, rotation, and soil testing practices: Economic and environmental implications. *American Journal of Agricultural Economics*, *80*(3), 494–511. https://doi.org/10.2307/1244552

Zeng, D., Alwang, J., Norton, G. W., Shiferaw, B., Jaleta, M., & Yirga, C. (2017). Agricultural technology adoption and child nutrition enhancement: Improved maize varieties in rural Ethiopia. *Agricultural Economics*, *48*(5), 573–586. https://doi.org/10.1111/agec.12358

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

How to cite this article: Kim J, Mason NM, Snapp S, Wu F. Does sustainable intensification of maize production enhance child nutrition? Evidence from rural Tanzania. *Agricultural Economics*. 2019;50:723–734. https://doi.org/10.1111/agec.12520