What drives sustainable intensification of maize production among smallholder farmers? Panel survey evidence from Tanzania

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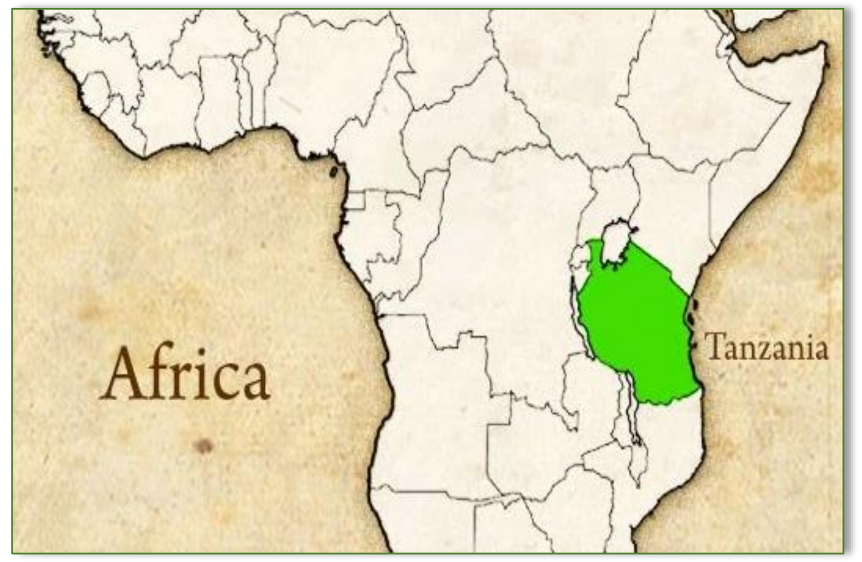
Introduction & Contributions



- Rising food demand and population growth pose serious challenges to agriculture in sub-Saharan Africa (SSA).
- Conventional agricultural intensification through the use of high-yielding crop varieties, inorganic fertilizer and pesticides may be insufficient to sustainably raise agricultural productivity and can have negative environmental effects (Petersen and Snapp 2015).
- **Sustainable intensification (SI)** could be a possible solution. SI is a **"process or system where yields are increased without adverse environmental impact and without the cultivation of more land"** (Pretty and Bharucha 2014, p. 1578).
- SI of maize production is important because maize is one of the main staple crops in Tanzania and about 75% of the total cultivated area in the country is planted to maize (Tanzania National Bureau of Statistics 2014).
- Soil fertility management (SFM) practices such as maize-legume intercropping and rotation, inorganic fertilizer, and organic fertilizer can contribute to the SI of maize production, **particularly when multiple SFM practices are combined**.
- Most previous studies on SI of maize production have focused on the adoption of individual practices but **little is known about the drivers of adoption of jointly implemented practices.**
- This paper estimates **the factors explaining the adoption of individual SFM practices and combinations thereof on Tanzanian farmers' maize plots.** It also improves on past studies by:
  1. Using panel data, which allows us to **control for time-constant unobserved heterogeneity.**
  2. Analyzing **the role of input and expected output prices**, which most previous studies on adoption of SFM practices have ignored.

Multinomial adoption selection model

- The maize growing farmer i's objective is to maximize their expected utility, U_i, by comparing the utility from m alternative packages of SFM practices on the maize plot.
- The expected utility, U_{ij}^*, from the adoption of the jth package can be expressed by

$$U_{ij}^* = \boldsymbol{X}_i\boldsymbol{\beta}_j + \varepsilon_{ij}$$

where $\boldsymbol{X}_i$ is a vector of exogenous covariates such as household characteristics, plot characteristics, and input and expected output prices; and ε_{ij} are the independently and identically distributed error terms.

- Let I be an index that denotes the farmer's choice among m alternative packages:

$$I = \begin{cases} 1 \text{ iff } U_{i1}^* > \max_{m \neq 1}(U_{im}^*) \\ \vdots \quad \vdots \quad \vdots \\ J \text{ iff } U_{iJ}^* > \max_{m \neq J}(U_{im}^*) \end{cases} \quad \text{for all } m \neq j$$

- In a multinomial logit model, the probability that farmer i will choose the jth package can be specified as: $P(I = j|\boldsymbol{X}_i) = \exp(\boldsymbol{X}_i\boldsymbol{\beta}_j) / [1 + \sum_{m=1}^{J} \exp(\boldsymbol{X}_i\boldsymbol{\beta}_m)]$

Data and Methodology

- Tanzania National Panel Survey (TZNPS): 3 waves of nationally-representative HH panel survey data are publicly available (2008/09, 2010/11, and 2012/13)
  - ✓ The sample consists of 3,265 HHs (2,603 HHs in rural areas and 1,202 in urban areas) in the 1st wave and there is very low attrition (4.84%) up to the 3rd wave
  - ✓ TZNPS merged with rainfall (NOAA CPC) and soil data (FAO Harmonized World Soil Database)
- **Analytical sample**
  - ✓ **3,071 observations on rural maize growing HHs (4,663 maize plots) in the last two waves** of the TZNPS; lose one wave due to inclusion of lagged output prices as proxies for expected output prices.

- **Practices analyzed**: 3 inputs/management practices that have the potential to contribute to SI of maize-based systems
  - ✓ i) **Inorganic fertilizer** ("*Intensification*"), ii) **Organic fertilizer** ("*Sustainable*"), iii) **Maize-legume intercropping** ("*Sustainable*")
  - ✓ Given 3 practices, there are **8 possible combinations at the plot level. We group these into 4 categories: None, Intensification, Sustainable, and SI** (Table 1).

Table 1. Maize SI categories and prevalence in Tanzania

Case	Inorganic fertilizer	Organic fertilizer	Maize-Legume Intercrop	# of maize plots	SI category	% of maize plots
1				2,156	None	46.2%
2	√			357	Intensification	7.7%
3		√		289	Sustainable	37.8%
4			√	1,225		
5		√	√	247		
6	√	√		86	Sustainable Intensification (SI)	8.3%
7	√		√	246		
8	√	√	√	57		

- **Methods**
  - ✓ **Multinomial logit regression of plot-level SI category** on explanatory variables, with "None" as the excluded category
  - ✓ **Correlated random effects (CRE)/Mundlak-Chamberlain device** to control for time-constant unobserved heterogeneity

Results

Table 2. CRE multinomial logit estimates of factors affecting maize SI category

Variables	Intensification	Sustainable	SI
Male-headed HH (1=yes)	-0.201	-0.095	-0.153
Age of HH head (years)	-0.122***	-0.008	-0.085**
Age of HH head squared	0.001*	0.000	0.001***
Education of HH head (years)	**0.093*** **	**0.029** **	**0.107*** **
Family labor (# of adults per acre)	0.125	0.053	0.302**
Family labor squared	-0.014	-0.003	-0.021**
Off-farm income (1=yes)	0.124	0.188	0.057
Total cultivated land (acres)	-0.052*	-0.035***	-0.035
Total cultivated land squared	0.000	0.000	-0.000
Farm assets (1,000 TSh)	0.000	0.000	0.000*
HH owns livestock (1=yes)	0.335	**0.551*** **	**0.740*** **
Access to credit (1=yes)	-0.070	0.089	0.471*
Government extension (1=yes)	**0.701*** **	-0.064	**0.625** **
Cooperative extension (1=yes)	**1.234*** **	0.073	**1.028*** **
Input subsidy voucher (NAIVs) (1=yes)	**3.197*** **	0.218	**2.967*** **
Plot distance from home (km)	-0.007**	-0.004	-0.004
Plot distance from main road (km)	-0.052**	-0.009	-0.029
Plot distance from major market (km)	-0.012**	-0.005*	-0.011**
HH has title deed for plot (1=yes)	**0.562***	0.188	**0.587** **
Plot size (acres)	**0.063*** **	**0.048*** **	**0.124*** **
Farmers' cooperative in village (1=yes)	0.747***	-0.156*	0.351**
Input supplier in village (1=yes)	-0.152	-0.023	0.245
Average total rainfall (mm)	0.005***	-0.001**	0.003***
Soil nutrient availability constraint (1=yes)	-0.264	**0.216** **	**0.371** **
Lagged maize price (TSh/kg)	-0.000	-0.000	-0.000
Lagged bean price (TSh/kg)	-0.000	-0.000	-0.000
Lagged groundnut price (TSh/kg)	**0.001***	-0.000	**0.000***
Inorganic fertilizer price (TSh/kg)	**0.001***	**0.001*** **	0.000

Notes: Reported figures are coefficients. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. Key findings in bold. "None" category excluded. Time-averages of HH-level variables were included in the model but not reported in Table 2.

Key Findings

- **Education of HH head, livestock ownership, more secure land tenure, plot size, and presence of soil nutrient constraints** are all positively correlated with the adoption of some or all SI categories relative to the "None" category.
- **Access to extension advice and input subsidies** are also positively correlated with "Intensification" and "SI".
  - ✓ For example, access to government extension increases the relative probability to **adopt "Intensification" by 101%** (2.01=exp(0.701)) and **adopt "SI" by 87%** (1.87=exp(0.625)) compared to "None".
- Of the input and output prices considered, only the lagged groundnut price and inorganic fertilizer price are statistically significant drivers of adoption of some SI categories. *However, the positive effects of these prices on the "Intensification" category (inorganic fertilizer use only) are counterintuitive and require further investigation.*

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