WAGENINGEN
UNIVERSITY & RESEARCH

Land fragmentation, climate change adaptation, and food security in the Gamo Highlands of Ethiopia

Cholo, T. C., Fleskens, L., Sietz, D., & Peerlings, J.

Please cite this publication as follows:

Cholo, T. C., Fleskens, L., Sietz, D., & Peerlings, J. (2019). Land fragmentation, climate change adaptation, and food security in the Gamo Highlands of Ethiopia. Agricultural Economics (United Kingdom), 50(1), 39-49. https://doi.org/10.1111/agec.12464

AGRICULTURAL ECONOMICS

Agricultural Economics 50 (2019) 39–49

Land fragmentation, climate change adaptation, and food security in the Gamo Highlands of Ethiopia

Tesfaye C. Cholo[a,b,*], Luuk Fleskens[a], Diana Sietz[a,c], Jack Peerlings[d]

[a]*Soil Physics and Land Management Group, Wageningen University and Research, The Netherlands*
[b]*Department of Development Economics, Ethiopian Civil Service University, Ethiopia*
[c]*Earth System Analysis, Research Domain 1, Potsdam Institute for Climate Impact Research, Member of the Leibniz Association, Potsdam, Germany*
[d]*Agricultural Economics and Rural Policy Group, Wageningen University and Research, The Netherlands*

Received 23 June 2017; received in revised form 21 August 2018; accepted 23 August 2018

Abstract

Household food security among smallholder farmers is sensitive to a variable and changing climate, requiring farmers in the Gamo Highlands of Ethiopia to adopt new land management practices to improve food security. Agricultural land in the Gamo Highlands is highly fragmented. The extent to which land fragmentation (LF) moderates the food security effects of sustainable land management (SLM) practices is unknown. This study used probit and Poisson models to explain this relationship. The study found that food insecurity was severe during the food shortfall season. LF provides more potential opportunities for improving food security than challenges. Furthermore, SLM practices had both positive and negative effects on food security and their effects were conditioned by the magnitude of LF. Reducing severe LF through the assembly of small parcels into larger heterogeneous plot clusters could enhance food security by exploiting synergies between adaptation practices and LF.

JEL classifications: Q18

Keywords: Land fragmentation; Sustainable adaptation; Food security; Ethiopia

1. Introduction

Climate change and variability are delaying the achievement of global food security (Schmidhuber and Tubiello, 2007). This is especially the case in Africa because African countries have not been able to increase productivity while decreasing greenhouse gas emissions (Majiwa et al., 2018), and the changing climate affects all components of food security (Kotir, 2011). According to the United Nations Food and Agricultural Organization (FAO), food security "exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (FAO, 2015). The adverse effects of climate change and variability on food security are most noticeable in less developed countries (Parrya et al., 2004). The agricultural sector (Kok et al., 2016; Mendelsohn et al., 2006) and the poor (Schmidhuber and Tubiello, 2007) are most vulnerable to climate change impacts in sub-Saharan Africa. Although progress has been made, in the years 2014–2016 the majority of the people still undernourished were in sub-Saharan Africa (FAO, 2015).

It is difficult to overcome the impacts of climate change and variability on agriculture, especially in less developed countries like Ethiopia (Conway and Schipper, 2011). Farmers in Ethiopia are unable to produce sufficient food for consumption, even during good rainfall years (Devereux and Sussex, 2000). This makes Ethiopia particularly vulnerable to climate change impacts (Stige et al., 2006) and famine (Von Braun and Olofinbiyi, 2012). Furthermore, climate change is projected to reduce net revenue per hectare in Ethiopia in the long term (Deressa and Hassan, 2009). Adapting agriculture to adverse climate impacts is a possible way out for farmers (Parry et al., 2007). Adaptation—defined as the "adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates, harm or exploits beneficial opportunities" (Parry et al., 2007, p. 869)—has been found to increase food security (Garrity et al., 2010), net farm revenue, and food production in sub-Saharan Africa (Di Falco, 2014; Di Falco and Veronesi, 2011).

This study focuses on sustainable land management (SLM) practices, as a subset of adaptation strategies, land

*Corresponding author. Tel.: +251912000344; fax: +251116463016. *E-mail address*: tesfaye.cholo@wur.nl or tesfayechofana@yahoo.com (T. C. Cholo).

 DOI: 10.1111/agec.12464

fragmentation (LF) and their combined effect on food security. SLM is defined as maintaining sufficient natural resources and ecosystem functions for an indefinite period, while meeting rising food and raw material demands (Fernandes and Burcroff, 2006). SLM increases resilience to climate change and variation (Liniger et al., 2011), reduces socioecological vulnerability (Kok et al., 2016) and, as a result, increases food security (Branca et al., 2013). Studies have also examined the effects of LF on food security, where LF is the cultivation of multiple scattered plots (Kawasaki, 2010). For instance, the number of plots decreases farm income (Bizimana et al., 2004), decreases productivity and causes yield loss in border areas (Van Dijk, 2003), decreases efficiency (Rahmana and Rahman, 2008), and increases production cost (Hung et al., 2007; Kawasaki, 2010) by increasing traveling time between plots (Niroula and Thapa, 2005). However, by considering costs and benefits of purchased inputs, Niroula and Thapa (2007) found a net positive effect of LF on farmers' income. Benefits mainly accrue as dispersed landholdings reduce production risks (Bentley, 1987; Blarel et al., 1992; Di Falco, 2014) by allowing crop diversification across seasons and agro-ecological zones, which in turn leads to food security improvements. Many papers have investigated the cost side of LF, while its benefits have been mostly ignored. The contribution of this study is to provide evidence that LF can be beneficial for food security. Moreover, although LF is expected to hold back farmers from effective use of SLM practices, the joint effects of SLM practices and LF on food security have not been studied yet. Thus, it was hypothesized that LF reduces the quality and quantity of SLM practices on remote plots, negatively affecting food security. However, at the same time by reducing production risks LF could enhance food security. Probit and Poisson models were used to analyze the food security consequences of the interactions between LF and SLM practices.

This article is structured into six sections. Section 2 describes the study area and explains how the data were collected. Section 3 sets out the analytical framework and section 4 presents the empirical models used. Section 5 provides the empirical results, followed by some concluding remarks in section 6.

2. Study area and data collection

The study area, the Gamo Highlands, is located in southwest Ethiopia. Although agriculture is sensitive to climate impacts (Zewdie, 2014), it is the dominant source of livelihood in Ethiopia (Croppenstedt and Muller, 2000), followed by weaving in the Gamo communities. Although the level of food security is generally low in Gamo, homes in Gamo communities are ringed by enset[1] to increase access to food and farmers can take advantage of a range of agroclimatic conditions. To facilitate the latter, farmers own multiple homes to decrease the burden of manure application in multiple plots and the time of commuting during production seasons. However, food availability changes over the year, and the poor have nothing to eat at the height of the food shortage season in Gamo (Mesfin et al., 2014).

The topography of the Gamo Highlands is mountainous, creating three distinct agroecological zones based on altitude. This requires farmers to diversify crops and production periods to suit each agroecological zone. Samberg et al. (2010) found that traditional farming practices in heterogeneous landscapes have resulted in diverse agrosystems in the Gamo Highlands.

The household level primary data used for this study were collected in the year 2015 from three kebeles (lowest level of administrative unit) in Dita district, namely, Done, Haila, and Ocholo-Badiga. These kebeles were selected because the local government's ongoing geographical data inventory is fully complete for these kebeles. A stratified random sampling technique was used to select farmers from these kebeles, based on multiple plot ownership and agroecological zones. Quantitative data were collected for 297 household heads. Food security data were inventoried for the month of May, which is usually the height of the food shortage season. A male and female were interviewed per household, but food security questions were specifically addressed to female respondents, because women are generally responsible for food in the Gamo communities. The geographic secondary data (i.e., plot location and size) were collected by experts employed by the local government using global positioning system devices to certificate land use rights. The district's average farm size of 1.7 hectares (ha) was fragmented into 21 plots, signalling a high level of fragmentation (exceeding the national average holding size of 1.0 ha fragmented into 2.4 plots) (Deininger and Jin, 2006).

3. Analytical framework

Climate change and variability are major challenges to household food security, requiring farmers to apply SLM practices to achieve food security. LF and SLM practices are assumed to have both synergetic and trade-off effects on the food production of smallholders. For this purpose, we examined whether food security is determined by the extent of LF (expressed using several LF indices), the use of SLM practices, and the interaction between LF and SLM. Given the lack of an available and appropriate theoretical model, we took an empirical approach, in which we first discuss both the dependent and explanatory variables.

3.1. Food security indicators

Maxwell (1996) identified two objective measures of food security, namely, gross household food production and

[1] Enset is an herbaceous species in the banana family. It is a perennial crop and its deep roots make it more resilient to drought than cereal crops so that it enhances food security. Moreover, it is used to feed cattle that provide manure which in turn is used to fertilize the soil.

Table 1
Frequency of occurrence of self-expressed answers to food security questions

Questions	Percentage of occurrence ($n = 297$)				Food security dimension
	i Never value = 0	ii Rarely value = 1	iii Sometimes value = 2	iv Often value = 3	
Q1. Worry about food	27	62	11	0	Stability
Q2. Unable to eat preferred food	12	80	8	0	Acceptability
Q3. Eat a limited variety of food	17	73	10	0	Diversity
Q4. Eat food that you didn't want to eat	18	72	10	0	Acceptability
Q5. Eat a small meal	46	50	4	0	Quantity
Q6. Skip a meal in a day	68	30	2	0	Quantity
Q7. No food to eat in a household	60	28	2	0	Quantity
Q8. Go to sleep at night hungry	68	30	2	0	Stability
Q9. Go 24 hours without eating food	80	19	1	0	Quantity
Q10. Adult skips meal to allow children to eat	33	65	2	0	Quantity
Q11. Borrow food or money to buy food	52	46	2	0	Quantity
Q12. Harvest immature crops	36	60	4	0	Quantity
Q13. Eat seed stock held to sow	16	81	3	0	Quantity
Q14. Household member eats grain	10	87	3	0	Diversity
Q15. Household member eats tubers	2	70	28	0	Diversity
Q16. Household member eats pulses	22	76	2	0	Diversity
Q17. Household member eats vegetables	25	72	3	0	Diversity
Q18. Household member eats fruit	74	26	-	0	Diversity
Q19. Household member eats dairy	34	65	1	0	Diversity
Q20. Household member ate sugar/honey	92	7	1	0	Diversity

Source: Survey data.

purchase, and the caloric intake of the household in the last 24 hours. However, these measures fail to take into account the vulnerability and sustainability components of food security. Hence, there has been a shift toward multiple subjective perception measures of food security, which can capture more dimensions of food security. Furthermore, in practice, it is difficult to choose the best indicator, hence, combining indicators can improve the measurement of food security (Maxwell et al., 2014).

The values for three food security indicators for the food shortfall period (i.e., May) in the Gamo Highlands were calculated using a series of questions[2] (see Table 1) developed by previous studies (Maxwell et al., 2014). These indicators (dependent variables) are (i) coping strategies index (CSI), (ii) household food insecurity access scale (HFIAS), and (iii) household dietary diversity scale (HDDS).

The CSI counts the occurrence and severity of behaviors engaged in by individuals when they face a shortage of money or resources to buy food (Maxwell et al., 2014). The CSI can be context specific and mainly captures the quantity or sufficiency elements of food security (Maxwell et al., 2014). To calculate the CSI, the value of eight study area-specific individual coping behaviors (indicated by Q2, Q5, Q6, and Q9–Q13 in Table 1) were added[3] together and the cutoff points of Maxwell et al. (2014) were used to determine the food security status of a household.

The HFIAS has been validated in both developed and developing regions (Gebreyesus et al., 2015). The HFIAS is determined from nine questions (Q1–Q9 in Table 1). These questions were designed to take into account household behavior with respect to insecure access to foodstuffs (Maxwell et al., 2014). The food security perception values of a household (columns i to iv in Table 1 for the first nine questions) were summed and the method of Coates et al. (2007) used to assign an HFIAS[4] category to each household.

To determine the HDDS of a household, the household perception values for Q14–Q20 under columns i to iv in Table 1 were added. The value of the HDDS ranges from 0 to 21 (Swindale and Bilinsky, 2006). The HDDS is the total number of food groups consumed by household members over the reference period. A more diversified diet implies a better

[2] Each question has four alternative answers. Never means the incidence never happened, rarely signifies the incidence happened 1 to 2 times, sometimes denotes the incidence happened 3 to 10 times, and often denotes the incidence happened more than 10 times per month. The corresponding food security indicator values range from 0 to 3.

[3] To compute CSI, add the values of each household's food security perception under columns i to iv in Table 1. If the sum of values added to a household i is between 0 and 2, 3 and 12, 13 and 40, or >40, then household i is categorized as food secure, mildly food insecure, moderately food insecure, or severely food insecure, respectively.

[4] HFIAS categories: 1. food secure, 2. mildly food insecure, 3. moderately food insecure and 4. severely food insecure. HFIAS category = 1 if [(Q1 $\leq$ 1) and Q2 to Q9 = 0], HFIAS category = 2 if [(Q1 $\geq$ 2 or Q2 $\geq$ 1 or Q3 = 1 or Q4 = 1) and Q5 to Q9 = 0], HFIAS category = 3 if [(Q3 $\geq$ 2 or Q4 $\geq$ 2 or 1 $\leq$ Q5 $\leq$ 2 or 1 $\leq$ Q6 $\leq$ 2) and Q7 to Q9 = 0], and HFIAS category = 4 if [Q5 = 3 or Q6 = 3 or Q7 $\geq$ 1 or Q8 $\geq$ 1 or Q9 $\geq$ 1].

Table 2
Summary statistics for variables

		%	Mean	*SD*	Min	Max
Dependent variables, dummy						
HFIAS	1 if household is food secure	6.7				
CSI	1 if household is food secure	5.1				
HDDS	Household Dietary Diversity score		4.8	1.5	0	8
Independent variables						
A) LF indicators						
Soil	Number of soil types		3.9	1.4	1	5
Homes	Number of homes		1.5	0.7	1	4
Plots	Number of plots		20.6	13.8	1	80
Farm	Land size, ha		1.7	1.7	0.1	15.3
SFI	Simpson index for LF		0.85	0.1	0	0.97
Distance	Nonoverlapping distance to plots, km		2.6	1.6	0.1	8.7
AEZ	1 if production in 2 agro-ecological zones	36				
B) SLM practices (dummy 1 = if SLM is applied)						
Seed	Quality seed use	76.1				
Manure	Manure use	94.0				
Indigenous	Indigenous tree planting	73.7				
Terrace	Stone terrace or soil bund	83.8				
Enset	Planting more enset	84.5				
Diversify	Crop diversification	58.9				
Legume	Legume–barley rotation	85.5				
Fertilizer	Kg of fertilizer applied per square meter		0.02	0.04	0	5
C) Socioeconomic characteristics						
Gender	1 if household head is male	90.6				
Literacy	1 if household head can read and write	21.6				
Dependence	Dependency ratio		113.5	95.9	0	1,100
Experience	Years of farming experience		33.8	15.6	0	76
Labor	Family labor size		3.5	2.3	0	15
Income	Off-farm income (in ‘000 Birr[6])		1.6	2.7	0	20
Remittance	1 if household receives remittances	11.5				
Asset	Number of assets		3.6	2.2	0	17
TLU	Tropical livestock units		3.5	2.7	0	22.9
Credit	1 if have access to credit when required	58.9				
Market	Walking distance to nearest market (hour)		1.9	1.1	0.3	6
Productivity	Yield per hectare (in ‘000 kg)		5.1	15.1	0	248.5
Landqul	Index for land quality		0.41	0.21	0	1
Shock	Number of shocks observed		10.4	4.7	0	20
	Observations					297

Source: Survey data.
[6] 1 Euro = 25 Birr.

caloric and protein intake and tends to capture the quality and diversity dimensions of food security (Maxwell et al., 2014).

The CSI measure showed the highest prevalence of food insecurity (95%) in the survey areas, followed by HFIAS with 93%.

3.2. *LF indicators*

Seven indicators were employed to measure LF (see Table 2). LF supports food security when the microenvironmental contrasts between nonadjacent plots of an owner are significant, whereas formal risk-reduction methods (such as credit) are limited or costly (Bentley, 1987; Blarel et al., 1992). LF enhances crop diversification and hence farm profitability (Di Falco et al., 2010). However, LF can also be detrimental to food supply by increasing inefficiency and decreasing productivity (Hung et al., 2007; Rahmana and Rahman, 2008). Based on this evidence it can be contended that LF provides an opportunity for food security which can be exploited while its detrimental effect should be minimized.

Hung et al. (2007) used the Simpson index, $[1 - (\sum_{i=1}^{n} a_i^2/A^2)]$, to compute LF—where a_i is the area of the ith plot in hectares, and A is the farm size in hectares, which equals the sum of the area of all n plots of the farm, $A = \sum_{i=1}^{n} a_i$. A Simpson index value of 1 implies severe LF, while a value of 0 represents perfect land consolidation.

3.3. *SLM practices*

SLM practices affect food security by influencing crop yield. The selection procedure of SLM practices as an adaptation strategy in this study was as follows: First, a survey of

13 potential SLM measures based on their importance to soil quality improvement and productivity was held. Second, farmers were asked about whether or not they have altered these SLM measures to adapt to climate change and variability they perceived in the last 25 years (i.e., changes or variations in temperature, precipitation, barley yield, or erosion features). If farmers respond to climate change they perceived, they are considered as adapters. Farmers are autonomous adapters if they are responding, although they did not perceive climate change and variability. Interestingly, almost 95% of farmers were purposely changing SLM practices to deal with climate change and variability. The remaining 5% were autonomous adapters and nonadapters. Finally, SLM measures that correlated with the farmers' perception of climate change and variability at the 10% significance level were considered for this study. Although the effects on food production of SLM practices vary according to the practice adopted, these practices generally have a positive effect (Branca et al., 2013). Thus, SLM practices are expected to increase food security.

3.4. Socioeconomic characteristics of households

A household's socioeconomic characteristics are expected to either positively or negatively affect food security. Food security is, for instance, negatively affected by the dependency ratio (Garrett and Ruel, 1999). The dependency ratio is defined as the ratio of household members aged less than 15 years plus age greater than 64 years to household members of working age (aged 15–64 years).

Off-farm income and family labor size can positively affect food security. Off-farm income is income earned by household members from agricultural employment on other people's farms, plus nonagricultural work and remittances. The presence of remittances is represented by a dummy, given lack of data on the size of remittances. Family labor size is the number of active population (age 15–64 years) in a household because age is an important determinant of earning capacity. Farmers use up assets and livestock during food shortage periods and restore these wealth components during food abundant periods (Demeke et al., 2011; Maxwell and Wiebe, 1999). Tropical livestock units (TLU)[5] as defined by Chilonda and Otte (2006) were used to standardize the measurement of livestock.

Market access is defined as the time needed to reach the relevant local market. Proximity to market increases access to off-farm income, information on inputs and transportation and, therefore, is expected to increase food security (Dorward et al., 2003). Unconstrained credit access is assumed to enhance food security, while access to credit from informal sources with high interest rate or formal sources with conditions for the use of credit (e.g., asset building) can decrease food security in the short term. Holden and Shiferaw (2004) note that credit for fertilizer improves food security.

[5] TLU = (0.5 × cattle) + (0.5 × horse) + (0.3 × donkey) + (0.6 × mule) + (0.1 × sheep) + (0.1 × goat) + (0.01 × chicken).

Barley yield per hectare expressed in thousands of kilograms is expected to increase food security (Feleke et al., 2005). Land quality was measured as a ratio of the number of plots with vigorous barley growth to the sum of plots with vigorous and stunted crop development. Land quality is expected to increase food production (Ndiritu et al., 2015). The frequent observation of climatic and nonclimatic shocks over the last five years is a sign that, in a good year, the stock of cereals retained from bumper harvests should be increased, and assets should be built, as a coping strategy to compensate for bad seasons. Thus, past scores for shocks observed are alerts and assumed to reinforce food security.

4. Empirical model

Food security is measured by either binary variables or by a discrete nonnegative integer variable; hence, correspondingly, probit and count data models are appropriate. For the probit model, let y_i be the observed food security status of the ith household: y_i equals 1 if household i is food secure and zero otherwise, while the level of household $i's$ food security y_i^* is the difference between the resources available for household i, r_i, to buy food and the consumption need of household i, c_i. From this, the latent (unobserved) variable y_i^* that can take all values in the range $(-\infty, \infty)$ is given by

$$y_i = \begin{cases} 1, & \text{if } y^* = r_i - c_i \quad > 0 \\ 0, & \text{if } y^* = r_i - c_i \leq \quad 0 \end{cases} \tag{1}$$

The probit model assumes that each subject has a binary food security response, which is given by

$$y_i^* = \alpha_0 + \sum_{k=1}^{8} \alpha_k \, SLM_{ik} + \sum_{j=1}^{7} \beta_j \, LF_{ij} + \sum_{k=1}^{8} \sum_{j=1}^{7} \gamma_{kj} \times SLM_{ik} \times LF_{ij} + \sum_{r=1}^{14} \delta_r X_{ir} + \varepsilon_i \tag{2}$$

where SML_{ik} is a land management practice k, applied as an adaptation strategy by household i, LF_{ij} is an LF indicator j of household i, and X_{ir} is a socioeconomic characteristic r of household i. And, α_0, α_k, β_j, γ_{kj}, and δ_r are coefficients to be estimated. The $SLM_{ik} \times LF_{ij}$ shows the interaction between the focus variables SLM_{ik} and the moderator variables LF_{ij}. The Poisson model is used when the equidispersion property of the model holds (i.e., when there is equality between the mean and variance). The Poisson model can be expressed as:

$$p\,(y_i) = \frac{\lambda^{y_i} \; \exp - \lambda_i}{y_i\,!}, \quad y_i = 0,\ 1,\ 2,\ 3,\ \ldots,\ I \tag{3}$$

where $p(y_i)$ is the probability of y (i.e., the frequency of occurrence of food insecurity for household i during the food shortage period) and λ_i is the expected food security/insecurity frequency. To estimate the Poisson model, the expected food insecurity frequency is assumed to be a function of the explanatory variables such that:

$$\lambda_i = \exp\left(\alpha_0 + \sum_{k=1}^{8}\alpha_k\, SLM_{ik} + \sum_{j=1}^{7}\beta_j\, LF_{ij} + \sum_{k=1}^{8}\sum_{j=1}^{7}\gamma_{kj}\times SLM_{ik}\times LF_{ij} + \sum_{r=1}^{14}\delta_r X_{ir} + \varepsilon_i\right) \quad (4)$$

The equidispersion property of the model can be tested by specifying

$$\mathrm{var}\,[y_i] = E\,[y_i]\,[1 + \theta\, E\,(y_i)] \quad (5)$$

If θ is not significantly different from zero, we can use the Poisson model. Otherwise the negative binomial model, which relaxes the equality assumption, can be used (Byrs et al., 2003). The negative binomial model regression is not the only way to model data that fail to hold the equidispersion property—the Poisson model with robust option can also be used (Cameron and Trivedi, 2009). In this empirical model, farmers could self-select into SLM practices. However, we believe this does not lead to an endogeneity problem as all farmers are applying at least one SLM practice. Thus, as long as all farmers are practicing some type of SLM, farmers do not have unique features that influence their adoption decisions and hence the outcome of adoption. Moreover, LF can be considered exogenous as land is state owned and there is no land market. Moreover, it is difficult to find a good control group because of a contamination problem as farmers are altering existing SLM or introducing new ones. For this, our estimation results should be interpreted as association rather than causal effects.

A likelihood ratio test is used by comparing the log likelihood of the unrestricted model to that of the reduced model to test three hypotheses. The first null hypothesis states that the food security effects of all the coefficients of SLM measures applied are assumed to be jointly equal to zero (i.e., $H_0 : \alpha_k = 0$). The second null hypothesis states that the LF indicators do not have a significant effect on household food security (i.e., $H_0 : \beta_j = 0$). The third null hypothesis states that the coefficients of the moderating effects of LF indicators on SLM practices are equal to zero (i.e., $H_0 : \gamma_{kj} = 0$).

5. Model results and discussion

The marginal effects of the estimated probit and Poisson models are presented in Table 4. For both models the Wald chi-squared test statistic rejected the hypothesis stating that all of the estimated coefficients are jointly equal to zero at the 1% significance level. The equidispersion property of the Poisson model was rejected at the 1% significance level; therefore, to address the equidispersion problem, we estimated a negative binomial model. However, for the negative binomial regression, the dispersion parameter was a missing value so we could not determine whether or not to use the negative binomial model to solve the problem. Therefore, the Poisson model with robust option was finally used (Cameron and Trivedi, 2009). Correlation coefficients between explanatory variables indicated in Table 2 were not more than 0.65; these correlations were considered low enough to avoid multicollinearity issues. However, some of the SLM practices (e.g., introduction of a new crop) were dropped because of multicollinearity with other practices.

A likelihood ratio test supported the importance of the LF indicators, adaptation measures, and their interaction in terms of influencing food security. For example, the first null hypothesis, that the effect of the adaptation measures used is simultaneously equal to zero, was rejected at the 5% significance level for probit models. The second null hypothesis, that the coefficients of the LF indicators are jointly equal to zero, was rejected at the 1% significance level for probit models. Moreover, the third null hypothesis, that the interaction effects of the LF indicators and SLM practices on food security are equal to zero, was rejected at the 1% significance level for probit models. However, these hypotheses were not rejected for the Poisson model and hence we did not control for interaction terms and SLM practices except for terracing for the Poisson model in Table 3. Terracing was included as it had a significant effect on food security.

5.1. Role of LF

Consistent with the expectation, LF improved different food security dimensions by reinforcing farmers' efforts to achieve food security. For instance, farmers who produced crops in two distinct agroecological zones (meaning farmers that had plots both in the midlands and highlands) were more likely to be food secure than farmers who produced crops in a single agroecological zone. For example, for HFIAS and CSI, respectively, farmers who were producing in two agroecological zones were found to be 11% and 7% more likely to be food secure than farmers who were producing in one agroecological zone. A marginal increase in the Simpson index increased the probability of food security, as measured by the HFIAS, by 83%. Moreover, a unit increase in either the number of homes owned or the number of plots increased the probability of food security, as measured by the CSI, by 11% or 0.4%, respectively. In addition, a unit increase in the number of soil types across separate plots cultivated led to a 0.2 additional dietary diversity score (see Table 4).

These results imply that LF allows farmers to diversify crops and crop planting periods to benefit from microenvironmental contrasts. This is a form of insurance in situations where a loss in production in one season is compensated by a gain in another season or the yield of one crop compensates for the loss of another. Moreover, growing a wide range of crops in separate agroecological zones allows farmers to produce

Table 3
Factors affecting food security

Variables	Probit models				Poisson model	
	HFIAS		CSI		HDDS	
LF indicators						
Soil	−0.087	(0.126)	−0.815***	(0.238)	0.045***	(0.017)
Homes	0.046	(0.228)	2.809***	(0.662)	−0.022	(0.027)
Plots	−0.012	(0.020)	0.110***	(0.033)	0.000	(0.002)
Farm	−0.018	(0.152)	0.068	(0.205)	0.006	(0.010)
SFI	144.458**	(72.066)	121.264***	(40.821)	0.290*	(0.170)
Distance	1.142***	(0.417)	−0.053	(0.537)	−0.011	(0.011)
AEZ	1.381***	(0.437)	1.768**	(0.754)	−0.007	(0.038)
SLM practices						
Seed	−6.109*	(3.399)	−0.226	(6.494)		
Indigenous	−9.010**	(4.406)	104.227***	(36.851)		
Terrace	−0.049	(3.868)	31.470*	(16.489)	0.160***	(0.061)
Enset	18.134**	(7.092)	−19.054	(17.894)		
Diversify	−4.254	(3.529)	−14.717***	(4.654)		
Legume	131.987**	(65.576)	6.038	(5.970)		
Fertilizer	−4.559	(5.854)	16.714***	(4.571)	−0.343	(0.666)
Interaction terms						
Seed × SFI	7.354*	(3.975)	3.379	(7.590)		
Indigenous × SFI	10.869**	(5.488)	−114.683***	(39.874)		
Terrace × SFI	−1.465	(4.565)	−38.272**	(18.607)		
Enset × SFI	−15.085**	(7.135)	23.379	(21.074)		
Diversify × SFI	5.022	(4.109)	15.018***	(5.420)		
Legume × SFI	−142.481**	70.181)	−8.787	(7.146)		
Diversify × Distance	−0.126	(0.249)	−1.010***	(0.348)		
Indigenous × Distance	−0.049	(0.226)	1.299**	(0.511)		
Enset × Distance	−1.206***	(0.417)	−0.331	(0.464)		
Socioeconomic characteristics						
Gender	1.211***	(0.435)			−0.019	(0.056)
Literacy	0.632	(0.494)	0.160	(0.681)	−0.002	(0.045)
Dependence	−0.008**	(0.003)	−0.027***	(0.010)	0.000	(0.000)
Experience	−0.004	(0.009)			−0.002	(0.001)
Labor	−0.069	(0.087)	−0.264*	(0.149)	0.007	(0.008)
Income	−0.017	(0.055)	0.049	(0.084)	0.006	(0.005)
Remittance	−1.231**	(0.488)	−1.581*	(0.949)	−0.011	(0.052)
Asset	0.206**	(0.082)	0.049	(0.128)	0.035***	(0.010)
TLU	−0.024	(0.061)	−0.209*	(0.108)	0.005	(0.006)
Credit	−0.367	(0.330)	2.841***	(0.908)	−0.096***	(0.032)
Market	0.030	(0.171)	1.715***	(0.459)	−0.016	(0.019)
Productivity	0.019***	(0.005)	0.065***	(0.016)	−0.000	(0.000)
Landqul	1.239*	(0.667)	4.859***	(1.344)	0.012	(0.081)
Shock	−0.002	(0.034)	0.045	(0.060)	0.005	(0.004)
Constant	−140.643**	(67.910)	−123.966***	(38.885)	0.964***	(0.145)
LR chi-square	105.79		129.12		95.20	
Prob > chi-square	0.000		0.000		0.000	
Observations	297		297		297	

Source: Survey data.
Note: Robust standard errors in parentheses.
***$P < 0.01$, **$P < 0.05$, *$P < 0.1$.

crops that ripen in different seasons over a year, enhancing access to fresh food and a healthy diet year round. Multiple homes ownership enhances food access, because it has a positive effect on the magnitude and quality of investment in land by decreasing commuting costs. Although cultivating multiple soils decreases food security (CSI), the overall result provides evidence for benefits of LF (Bentley, 1987; Di Falco et al., 2010).

5.2. *Role of SLM practices*

Although farmers had limited access to costly quality seed and fertilizers, the use of these inputs increased the probability of being food secure, as measured by CSI (7% and 65%, respectively). The use of quality seed has the potential to increase productivity and income (Teklewold et al., 2013). Berger et al. (2017) found that new wheat and maize varieties are effective

Table 4
Marginal effects

Variables	Probit models				Poisson model	
	HFIAS		CSI		HDDS	
LF indicators						
Soil	−0.007	(0.010)	−0.032***	(0.009)	0.216***	(0.081)
Homes	0.004	(0.018)	0.110***	(0.025)	−0.103	(0.131)
Plots	−0.001	(0.002)	0.004***	(0.001)	0.001	(0.009)
Farm	−0.001	(0.012)	0.003	(0.008)	0.030	(0.046)
SFI	0.828**	(0.352)	0.684	(0.435)	1.389*	(0.816)
Distance	−0.008	(0.008)	0.012	(0.009)	−0.051	(0.054)
AEZ	0.108***	(0.035)	0.069***	(0.027)	−0.035	(0.184)
SLM practices						
Seed	0.016	(0.020)	0.067***	(0.015)		
Indigenous	0.002	(0.029)	0.061***	(0.024)		
Terrace	−0.161**	(0.067)	−0.131***	(0.033)	0.768***	(0.291)
Enset	−0.001	(0.025)	−0.008	(0.032)		
Diversify	−0.020	(0.027)	−0.168***	(0.018)		
Legume	−0.033	(0.045)	−0.086**	(0.043)		
Fertilizer	−0.355	(0.470)	0.652***	(0.182)	−1.647	(3.191)
Socioeconomic characteristics						
Gender	0.094**	(0.037)			−0.091	(0.270)
Literacy	0.049	(0.038)	0.006	(0.027)	−0.009	(0.214)
Dependence	−0.001**	(0.000)	−0.001***	(0.000)	0.001	(0.001)
Experience	−0.000	(0.001)			−0.008	(0.006)
Labor	−0.005	(0.007)	−0.010*	(0.006)	0.034	(0.039)
Income	−0.001	(0.004)	0.002	(0.003)	0.027	(0.024)
Remittance	−0.096**	(0.041)	−0.062*	(0.036)	−0.051	(0.249)
Asset	0.016**	(0.007)	0.002	(0.005)	0.169***	(0.048)
TLU	−0.002	(0.005)	−0.008*	(0.004)	0.023	(0.031)
Credit	−0.029	(0.025)	0.111***	(0.033)	−0.462***	(0.154)
Market	0.002	(0.013)	0.067***	(0.019)	−0.074	(0.089)
Productivity	0.002***	(0.000)	0.003***	(0.001)	−0.002	(0.002)
Landqul	0.096*	(0.054)	0.189***	(0.053)	0.057	(0.386)
Shock	−0.000	(0.003)	0.002	(0.002)	0.022	(0.019)
LR chi-square	105.79		129.120		95.200	
Prob > chi-square	0.000		0.000		0.000	
Observations	297		297		297	

Source: Survey data.
Note: Standard errors in parentheses.
***$P < 0.01$, **$P < 0.05$, *$P < 0.1$.

adaptation measures in Ethiopia, especially when accompanied by credit availability and a fertilizer subsidy. The probability of being food secure, as represented by CSI, was 6% higher for families that planted native trees than for families that did not plant native trees. Indigenous trees are commonly planted in the Gamo Highlands, to control erosion and enhance soil fertility. Sanchez et al. (1979) observed that a shift toward agroforestry practices is a sustainable way to improve food production in the densely populated areas of East Africa where farm sizes are small.

Practicing either crop diversification or legume–barley rotation decreased the possibility of a family being food secure, as represented by the CSI, by 17% or 9%, respectively. However, multiple crop production is promoted for dietary diversity and to reduce overall production risks in subsistence-based farming (Pellegrini and Tasciotti, 2014). We contend that diversification possibly becomes more effective when farmers diversify effectively to take advantage of microenvironmental contrasts by selecting crop species and varieties best suited to the plots owned.

Terracing was found to decrease the probability of being food secure in the Gamo Highlands, as reflected by the HFIAS and CSI (16% and 13%, respectively). However, Shively (1999) found that terracing increases food production. This unexpected result can probably be attributed to the fact that farmers who practice terracing more frequently cultivate sloped plots that are less fertile and more eroded than farmers who do not terrace. Hence, in the short term, terracing decreases the probability of being food secure. Moreover, terraces that are constructed from soil and are renewed in each production season cannot sustainably improve soil fertility. However, terracing led to 0.8 additional dietary diversity score. The food security effect of SLM practices is partly inconsistent with studies by Di Falco et al. (2011) and Teklewold et al. (2013) that were conducted in the region. These differential food security effects of SLM practices may stem from differences in SLM practices used, the period in which food security was measured and indicators used to measure food security. Notwithstanding, a review of studies supports the overall effects of SLM practices on food security found (Branca et al., 2013; Dutilly-Diane et al., 2003). These studies found that SLM results in higher output, although the magnitude and variability of results vary with the specific practices employed and rainfall distribution.

5.3. *Moderating role of the LF indicators*

The food security effects of the SLM practices employed were a function of the level of LF indicators. Our discussion in this section focuses on reduced models (i.e., models without interaction terms for Eqs. (2) and (4)). It is impossible to estimate a separate effect of SLM measures on food security for a model with interaction terms because the value of interaction terms can change with the value of component terms (Williams, 2012). For ease of exposition, we presented in Table 5 marginal effect of SLM practices at the representative values of Simpson index 0.1, 0.3, 0.5, 0.7, and 0.9, although we estimated marginal effects for index values ranging from 0 to 0.97. Moreover, we reported in Table 5 the marginal effects for SLM practices that have a significant effect.

For food security measured as HDDS, terracing on average increased dietary diversity by a factor of 0.77 for the reduced model while other practices left dietary diversity unaffected. The marginal effect of terracing on dietary diversity increased from 0.62 to 0.78 as the Simpson index increased from 0.1 to 0.9 for the reduced model. For food security measured as CSI, on average, quality seed use increased the probability of being food secure by 6%. Quality seed use increased the probability of being food secure by 13% and 5% when the Simpson index was 0.1 and 0.9, respectively. The results in Table 5 imply that the marginal food security effects of SLM practices that increased the probability of being food secure were decreasing as the Simpson index increased, except for terracing. However, the marginal food security effects of SLM practices that decreased the probability to be food secure were decreasing as the Simpson index increased. The overall result implies that the negative food security effects of SLM practices are dominant when LF becomes higher.

Table 5
Marginal effect of SLM practices at the representative values of Simpson index

Value of Simpson index	CSI				HDDS
	Seed	Indigenous	Diversify	Legume	Terrace
0.1	0.125^{**}	0.267^{***}	-0.305^{***}	-0.107^{**}	0.618^{**}
0.3	0.116^{**}	0.249^{***}	-0.284^{***}	-0.099^{**}	0.654^{**}
0.5	0.105^{**}	0.225^{***}	-0.256^{***}	-0.098^{**}	0.693^{**}
0.7	0.083^{**}	0.179^{***}	-0.204^{***}	-0.071^{**}	0.735^{**}
0.9	0.054^{**}	0.117^{**}	-0.133^{***}	0.047^{**}	0.778^{**}

Source: Survey data.
$^{***}P < 0.01$, $^{**}P < 0.05$, $^{*}P < 0.1$.

5.4. *Role of household socioeconomic factors*

Socioeconomic variables, for instance, asset ownership and being male, increased the probability to be food secure while the dependence ratio decreased the probability to be food secure. These results are consistent with Feleke et al. (2005) and Guo (2011), respectively.

Moreover, increasing land productivity by a kilogram increased the likelihood of being food secure by 0.2% and 0.3%, respectively for HFIAS and CSI. These findings are consistent with Ndiritu et al. (2015). A unit increase in land quality enhanced the probability of being food secure by 19% and 10% for the food security indices CSI and HFIAS, respectively. The positive effect of productivity and land quality implies that investment in land quality improves food security in the long term.

6. Conclusion

Climate change and variability are worsening the food security status of households that rely on subsistence agriculture that is characterized by LF. The adoption of SLM practices is one way to deal with adverse climate effects. This study shows that although farmers were adopting SLM practices, the share of food insecure households in the Gamo Highlands of Ethiopia was high, ranging from 93% to 95% depending on the indicator used.

The empirical results confirm that LF provides more potential opportunities for improving food security than challenges. LF indicators (such as cultivation in distinct agroecological zones, the Simpson index, and multiple home ownership) increased the probability of a household being food secure. Furthermore, LF increases farm diversity (including soil types and the fertility of plots cultivated), leading to diversity in crops grown and production seasons, allowing farmers to reduce risks and harvest fresh produce throughout the year, thereby improving food security. Finally, production across different agroecological zones helps to cope with price fluctuations and balances food demand, thus increasing food security. The food security effects of the SLM practices employed range from negative to positive. Moreover, the food security effects of the SLM practices employed to deal with climate change and variability were positively or negatively moderated by the level of LF.

Overall, the findings imply that increasing the quality and the quantity of SLM practices is important to cope with the adverse impacts of climate change and variability on food security. This has some implications for policy makers. First, the best SLM practices are not always implemented because of lack of resources to buy inputs such as fertilizer and seed of high yielding varieties (see also Berger et al., 2017). Therefore, it is important to establish adequate access to credit, e.g., via microcredit. Moreover, the availability, variety, and quality of inputs like fertilizer and seeds should be improved to enhance adaptation. Second, short- and long-term maintenance of SLM practices is important to enhance effectiveness of adaptation practices, but maintenance is often overlooked in Ethiopia. Extension workers, experts, and farmers could collaborate to plan and implement short- and long-term maintenance services. Third, farmers are shifting to cereal crops and decreasing the use of enset for food, while enset is a perennial crop that is more drought tolerant and has higher yields than cereals. The government could promote the use of enset for different livelihood activities (such as food, income generation, and forage). Finally, farmers' food security can also be enhanced by taking advantage of synergies between SLM and LF and resolving their contrasting effects. Now, LF is largely exogenous to farmers—which is why we do not consider endogeneity problems in our estimation—but it is clear that the assembling of plots into larger heterogeneous clusters of the plots could help farmers to become more food secure. Plot assembly may be possible through government assistance with the voluntary bartering of plots, introduction of an inheritance scheme that avoids further plot disintegration, and the creation of a land rental market by introducing land privatization. Each of these policy options requires additional research. Given the benefits and challenges of the high level of LF in the study area, further research is needed to investigate LF and its effects.

This study has some caveats. First, the analysis of longitudinal data would have been useful to capture the dynamics of food security and weather. For instance, crop loss is not uniform over periods; hence, the food security status of subsistence agricultural households varies across seasons and years. Second, although the subjective perception measures of food security reflect the farmers' reality, these measures fail to capture elements that would be better considered using objective yardsticks, such as calories. Despite these caveats, this study contributes to the body of literature on food security under changing and variable climate and in an area where there is limited access to formal risk reduction measures (such as insurance) by studying how LF moderates the food security effects of SLM practices.

References

Bentley, J., 1987. Economic and ecological approaches to land fragmentation: In defense of a much-aligned phenomenon. Annu. Rev. Anthrop. 16, 31–67.

Berger, T., Troost, C., Wossen, T., Latynskiy, E., Tesfaye, K., Gbegbelegbe, S., 2017. Can smallholder farmers adapt to climate variability, and how effective are policy interventions? Agent based simulation results for Ethiopia. Agric. Econ. 48, 693–706.

Bizimana, C., Nieuwoudt, W.L., Ferrer, S.R., 2004. Farm size, land fragmentation and economic efficiency in southern Rwanda. Agrekon. 43, 244–262.

Blarel, B., Hazell, P., Place, F., Quiggin, J., 1992. The economics of farm fragmentation: Evidence from Ghana and Rwanda. World Bank Econ. Rev. 6, 233–254.

Branca, G., Lipper, L., McCarthy, N., Jolejole, M.C., 2013. Food security, climate change, and sustainable land management. A review. Agron. Sustain. Dev. 33, 635–650.

Byrs, A.L., Alloreb, H., Gillb, T.M., Peduzzia, P.N., 2003. Application of negative binomial modeling for discrete outcomes: A case study in aging research. J. Clin. Epidemiol. 56, 559–564.

Cameron, A.C., Trivedi, P.K., 2009. Microeconometrics Using Stata. Stata Press, College Station, TX.

Chilonda, P., Otte, J., 2006. Indicators to monitor trends in livestock production at national, regional and international levels. Accessed December 2016, available at http://www.lrrd.org/lrrd18/8/chil18117.htm

Coates, J., Swindale, A., Bilinsky, P., 2007. Household Food Insecurity Access Scale (HFIAS) for Measurement of Food Access: Indicator Guide. Food and Nutrition Technical Assistance Project, Academy for Educational Development, Washington, DC.

Conway, D., Schipper, E.L.F., 2011. Adaptation to climate change in Africa: Challenges and opportunities identified from Ethiopia. Global Environ. Change. 21, 227–237.

Croppenstedt, A., Muller, C., 2000. The impact of farmers' health and nutritional status on their productivity and efficiency: Evidence from Ethiopia. Econ. Devel. Cult. Change. 48, 475–502.

Deininger, K., Jin, S., 2006. Tenure security and land-related investment: Evidence from Ethiopia. Europ. Econ. Rev. 50, 1245–1277.

Demeke, A.B., Keil, A., Zeller, M., 2011. Using panel data to estimate the effect of rainfall shocks on smallholders food security and vulnerability in rural Ethiopia. Clim. Change. 108, 185–206.

Deressa, T.T., Hassan, R.M., 2009. Economic impact of climate change on crop production in Ethiopia: Evidence from cross-section measures. J. African Econ. 18, 529–554.

Devereux, S., Sussex, I., 2000. Food insecurity in Ethiopia. London: A DFID Ethiopia Seminar. Accessed December 2016, available at https://www.ids.ac.uk/files/FoodSecEthiopia4.pdf.

Di Falco, S., 2014. Adaptation to climate change in Sub-Saharan agriculture: Assessing the evidence and rethinking the drivers. Europ. Rev. Agr. Econ. 41, 405–430.

Di Falco, S., Penov, I., Aleksiev, A., Van Rensburg, T.M., 2010. Agrobiodiversity, farm profits and land fragmentation: Evidence from Bulgaria. Land Use Pol. 27, 763–771.

Di Falco, S., Veronesi, M., 2011. On adaptation to climate change and risk exposure in the Nile basin of Ethiopia. Accessed December 2016, available at https://www.researchgate.net/profile/Salvatore_Di_Falco/publication/239805216.

Di Falco, S., Veronesi, M., Yesuf, M., 2011. Does adaptation to climate change provide food security? A micro-perspective from Ethiopia. Amer. J. Agr. Econ. 93, 829–846.

Dorward, A., Poole, N., Morrison, J., Kydd, J., Ure, I., 2003. Markets, institutions and technology: Missing links in livelihoods analysis. Dev. Pol. Rev. 21, 319–332.

Dutilly-Diane, C., Sadoulet, E., Janvery, A., 2003. Household behaviour under market failures: How natural resource management in agriculture promotes livestock production in the Sahel. J. Afr. Econ. 12, 343–370.

FAO, 2015. The state of food insecurity in the world 2015. Meeting the 2015 International Hunger Targets: Taking Stock of Uneven Progress. Food and Agricultural Organization (FAO), Rome.

Feleke, S.T., Kilmer, R.L., Gladwin, C.H., 2005. Determinants of food security in Southern Ethiopia at the household level. Agric. Econ. 33, 351–363.

Fernandes, E.C., Burcroff, R., 2006. Sustainable Land Management: Challenges, Opportunities, and Trade-Offs. World Bank, Washington, DC.

Garrett, J.L., Ruel, M.T., 1999. Are determinants of rural and urban food security and nutritional status different? Some insights from Mozambique. World Devel. 27, 1955–1975.

Garrity, D.P., Akinnifesi, F.K., Ajayi, O.C., Weldesemayat, S.G., Mowo, J.G., Kalinganire, A., Larwanou, M., Bayala, J., 2010. Evergreen agriculture: A robust approach to sustainable food security in Africa. Food Sec. 2, 197–214.

Gebreyesus, S.H., Lunde, T., Mariam, H.D., Woldehanna, T., Lindtjørn, B., 2015. Household food insecurity access scale (HFIAS) developed internationally to measure food insecurity valid in urban and rural households of Ethiopia? BMC Nutrit. 1, 2–10.

Guo, B., 2011. Household assets and food security: Evidence from the survey of program dynamics. J. Family Econ. Issues. 32, 98–110.

Holden, S., Shiferaw, B., 2004. Land degradation, drought and food security in a less-favoured area in the Ethiopian highlands: A bio-economic model with market imperfections. Agric. Econ. 30, 31–49.

Hung, V.P., MacAulay, T.G., Marsh, P.S., 2007. The economics of land fragmentation in the north of Vietnam. Australian J. Agr. Resource Econ. 51, 195–211.

Kawasaki, K., 2010. The costs and benefits of land fragmentation of rice farms in Japan. Australian J. Agr. Resource Econ. 54, 509–526.

Kok, M., Lüdeke, M., Lucas, P., Sterzel, T., Walther, C., Janssen, P., Sietz, D., De Soysa, I., 2016. A new method for analysing socio-ecological patterns of vulnerability. Regi Env. Chg. 16, 229–243.

Kotir, H.J., 2011. Climate change and variability in sub-Saharan Africa: A review of current and future trends and impacts on agriculture and food security. Environ. Dev. Sustain. 13, 587–605.

Liniger, H., Mekdaschi-Studer, R., Hauert, C., Gurtner, M., 2011. Guidelines and Best Practices for Sub-Saharan Africa, Field Application. FAO, Rome.

Majiwa, E., Lee, B.L., Wilson, C., 2018. Increasing agricultural productivity while reducing greenhouse gas emissions in Sub-Saharan Africa: Myth or reality? Agric. Econ. 49, 183–192.

Maxwell, D., Vaitla, B., Coates, J., 2014. How do indicators of household food insecurity measure up? An empirical comparison from Ethiopia. Food Pol. 47, 107–116.

Maxwell, D., Wiebe, K., 1999. Land tenure and food security: Exploring dynamic linkage. Devel. Change. 30, 825–849.

Maxwell, D.G., 1996. Measuring food insecurity: The frequency and severity of "coping strategies." Food Pol. 21, 291–303.

Mendelsohn, R., Dinar, A., Williams, L., 2006. The distributional impact of climate change on rich and poor countries. Environ. Devel. Econ. 11, 159–178.

Mesfin, M., Gebrerufael, G., Feleke, W., 2014. Enhancing household food security through Irish potato production in Gamo Highlands of southern Ethiopia. Scholarly J. Agri Sci. 4, 410–419.

Ndiritu, S., Kassie, M., Shiferaw, B., 2015. Determinants of food security in Kenya, a gender perspective. Accessed December 2016, available at https://ccafs.cgiar.org/publications/determinants-food-security-kenya-gender-perspective.

Niroula, G.S., Thapa, G.B., 2005. Impacts and causes of land fragmentation and lessons learned from land consolidation in South Asia. Land Use Pol. 22, 358–372.

Niroula, G.S., Thapa, G.B., 2007. Impacts of land fragmentation on input use, crop yield and production efficiency in the mountains of Nepal. Land Deg Devel. 18, 237–248.

Parry, M., Canziani, O., Palutikof, J., van der Linden, P., Hanson, C., 2007. Climate Change 2007: Impacts, Adaptation and Vulnerability. Cambridge University Press, Cambridge.

Parrya, M.L., Rosenzweigb, C., Iglesiasc, A., Livermored, M., Fischere, G., 2004. Effects of climate change on global food production under SRES emissions and socio-economic scenarios. Global Environ. Change. 14, 53–67.

Pellegrini, L., Tasciotti, L., 2014. Crop diversification, dietary diversity and agricultural income: Empirical evidence from eight developing countries. Can. J. Devel. Stud. 35, 211–227.

Rahmana, S., Rahman, M., 2008. Impact of land fragmentation and resource ownership on productivity and efficiency: The case of rice producers in Bangladesh. Land Use Policy. 26, 95–103.

Samberg, L.H., Shennan, C., Zavaleta, E.S., 2010. Human and environmental factors affect patterns of crop diversity in an Ethiopian highland agroecosystem. Prof. Geog. 62, 395–408.

Sanchez, P.A., Buresh, R.J., Leakey, R.R., 1979. Trees, soils, and food security. Philos. Trans. R. Soc. Lond., Ser. B: Biol. Sci. 352, 949–961.

Schmidhuber, J., Tubiello, F.N., 2007. Global food security under climate change. PNAS. 104, 19703–19708.

Shively, E.G., 1999. Risks and returns from soil conservation: Evidence from low-income farms in the Philippines. Agric. Econ. 21, 53–67.

Stige, L.C., Stave, J., Chan, K., Ciannelli, L., Pattorelli, N., Glantz, M., Herren, H., Stenseth, N., 2006. The effect of climate variation on agro-pastoral production in Africa. PNAS. 103, 3049–3053.

Swindale, A., Bilinsky, P., 2006. Household Dietary Diversity Score (HDDS) for Measurement of Household Food Access: Indicator Guide. Food and Nutrition Technical Assistance Project, Academy for Educational Development, Washington, DC.

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

Van Dijk, T., 2003. Scenarios of central European land fragmentation. Land Use Pol. 20, 149–158.

Von Braun, J., Olofinbiyi, T., 2012. Famine and Food Insecurity in Ethiopia. Food Policy for Developing Countries: Case Studies. Cornell University Press, Ithaca, New York.

Williams, R., 2012. Using the margins command to estimate and interpret adjusted predictions and marginal effects. The Stata J. 12, 308–331.

Zewdie, A., 2014. Impacts of climate change on food security: A literature review in sub Saharan Africa. Earth Sci. Chg. 5, 1–4.

Supporting Information

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