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Adoption of climate change adaptation strategies by maize-dependent smallholders in Ethiopia

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ABSTRACT

Climate change is an environmental process that is among the most limiting factors for increasing or even maintaining food production by small-farmer communities in Sub Saharan Africa (SSA). Adoption of climate change adaptation strategies that increase agricultural productivity and at the same time building farmers' resilience capacity has become a top policy priority in SSA. In this study, we investigate how maize-dependent smallholders in Ethiopia adapt to climate change. Both household and plot-level data were collected, and subsequently analysed by a multivariate probit regression model. Results show that most climate change adaptation strategies implemented by maize-dependent smallholders, are complementary. Combining conservation tillage, mixed maize-legume cropping and terracing along with the use of drought-resistant maize varieties allows farmers to increase productivity while building resilience to climate change more than a subset of these strategies. Findings indicate that the likelihood of adopting soil and water conservation practices, drought-resistant maize varieties and chemical fertilizers significantly increase among young and male-headed households as well as farmers having confidence in extension agents and membership in local organisations. Hence, policies should aim at further building agricultural extension agents' capacity by providing effective and continuous education and training on climate change impacts and responses. Promoting family ties and household memberships in local organisations through facilitating mutual cooperation and communication among farming communities would help to foster adoption of climate change adaptation strategies.

1. Introduction

Ensuring household food security through sustaining crop production continues to be a central challenge for rural farming households in Sub Saharan Africa (SSA). Rapid soil degradation caused by human population pressure (AGRA (Aliance for a Green Revolution in Africa) (2014)), poor access to agricultural extension and advisory services (Falco, 2014), and financial constraints (Wainaina et al., 2016) are reducing productivity and yields for the major crops such as maize (*Zea mays* L.) in SSA(Asfaw et al., 2013; Boansi et al., 2017; Mulwa et al., 2017).

Maize is the major staple food crop in SSA and is predominantly produced by smallholder farmers on a small farm plot (often less than five ha) using family labour. Because of its many cultivars that allow maize to be grown in diverse agro-ecological zones (Abate et al., 2015) and high economic as well as nutritional values (Adimassu et al., 2014), the species is the most important cereal crop for ensuring food security (AGRA (Aliance for a Green Revolution in Africa) (2014); Abate et al., 2015; Kassie et al., 2013). However, maize-dependent smallholders in SSA are particularly vulnerable to multiple environmental changes. This is because most maize-dependent smallholders in SSA produce on fragile, degraded terrain with poor soil fertility (Adimassu et al., 2014). Small maize producers often have poor access to input and output markets, credit service and weather information, and thus they are subject to high production costs and low net revenue. Climate change adds to these challenges not only through reducing soil moisture regime, but also by changing the frequency and duration of rainy seasons. Frequent change in seasonal rainfall may reduce mean maize yields and

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its quality as well as increase yield variability by causing water stress during its growth, flowering and grain filling stages (Lobell et al., 2011). In North Ethiopia, Falco (2014) showed that erratic rainfall exacerbate farmers' vulnerability to climate change by reducing availability of and access to agricultural water, and hence resulting in dry spell and drought stress conditions. Increase in frequency and intensity of drought is triggering distress scale of productive livelihood assets such as soil moisture and organic matter content, thereby reducing productivity and future investment capacity. Such adverse climate change impacts would in turn perpetuate poverty and malnutrition through reducing production, income and consumption among maize-dependent smallholders (World Bank (2008); Conway and Schipper, 2011).

In light of these multi-dimensional challenges, international donors, private agencies and public agricultural extension institutions are now actively promoting efforts to help maize-dependent smallholders adapt to climate change in SSA in general, and Ethiopia in particular (AGRA (Aliance for a Green Revolution in Africa) (2014); Asfaw et al., 2013; Cairn et al., 2013). Most agricultural extension efforts provide technological packages, particularly improved (high-yielding, disease-resistant and drought-tolerant) maize varieties and mineral fertilizers for increasing productivity and at the same time dealing with climate change risks (Kaliba et al., 2000; Ndiritu et al., 2014). Such technology packages are provided by extension agents through little emphasize on alternative, context-specific and low-cost inputs that provide better economic and environmental outcomes when adopted jointly than using independently (Davis, 2009).

Despite the fact that the use of external-input agricultural technologies might increase yields and thus even reduce poverty in the short run, they are often adopted at the expense of other agro-ecosystem services such as soil nutrient recycling, water and land use efficiency, food quality and carbon sequestration (Vignola et al., 2015), and as a result in the long run have a negative impact on production and poverty reduction. Also in Ethiopia, promotion of high-cost agricultural technologies alone could not realize their full productivity potential due to (i) rapid soil nutrient depletion because of intensive cultivation in combination with unexpected flood incidents (Feder et al., 1981; Kassie et al., 2015); (ii) declining soil moisture content due to high rainfall variability and more recurrent drought events (Ndiritu et al., 2014; Shiferaw et al., 2014); and (iii) reducing soil organic matter content following inefficient and inappropriate use of the chemical fertilizer (Vignola et al., 2015; Wainaina et al., 2016). Such productivity and production challenges are especially pronounced when the costs of fertilizers and improved crop varieties in the local market become unfordable for the farming communities.

As a result, adoption of conservation tillage, crop diversification, crop varietal selection, and Soil and Water Conservation (SWC) practices in combination with chemical fertilizers and improved maize varieties can help enhance productivity by maintaining soil nutrient and moisture contents as well as reducing erosion and run-off rates. Such agronomic and natural resource management measures may allow to mitigate emissions from fertilizers and manures by acting as a potential carbon sink (Kassie et al., 2015; Piya et al., 2013; Shiferaw et al., 2014). Mulwa et al. (2017) showed that simultaneous use of multiple adaptation strategies at a small farm setting provides higher yields and additional household income by reducing the financial constraints to implement managed irrigation system. The use of crop rotation and organic manure in combination with high-cost improved seeds and mineral fertilizers can maintain soil nutrient and biomass contents. Such integrated adaptation strategies would in turn provide an opportunity for utilizing the existing land and labour to build livelihood resilience through sustainable farm intensification and diversification (Kassie et al., 2015).

Farm level climate change adaptation strategies can be interrelated to one another when the adoption of specific adaptation strategies either simultaneously or sequentially promote the use of other strategies (Asfaw et al., 2013; Kassie et al., 2015). Yu et al. (2008) indicate that as the number of adaptation strategies increases, they are likely to be interdependent, even if one strategy substitutes another when considered separately. For example, the potential of drought tolerant crop varieties may be promoted through use of animal manure and crop residue that have potential to increase soil water retention and moisture content during the dry seasons (Wainaina et al., 2016). Such interdependency provides an incentive to smallholder farmers in order to implement multiple climate change adaptation strategies simultaneously at once or one after another (Kassie et al., 2013; Ndiritu et al., 2014).

Most existing climate change vulnerability studies focus on the adoption of specific types of adaptation strategies like crop diversification (Thornton and Herrero, 2014), changing crop types and varieties (Fisher et al., 2015) and irrigation water use (Bedeke and Beyene, 2013) independently. Although a focus on an individual adaptation strategy is necessary to deal with a particular climate risk, this strategy alone may not be sufficient for addressing current and emerging climate change risks that are highly complex, dynamic and uncertain (Boansi et al., 2017; Falco, 2014). For example, in a specific drought-prone setting, both dry spell and erratic rainfall may occur at simultaneously, and thus farmers would be subjected to productivity, income and consumption losses within the same growing season. The joint occurrence of different climate perturbation within a specific production period dictates the use of diverse adaptation strategies to take advantages of reducing risk and increasing benefit to the rural poor (Boansi et al., 2017). In this case, understanding how farmers are adopting strategies to recover from, cope with and adapt to multiple climate risks provides information for developing future adaptation plans. Although there are some studies that explored the extent of adoption of sustainable intensification practices in SSA (Kassie et al., 2013; Ndiritu et al., 2014), to the best of our knowledge, a very little research has been done to explore the degree of relationship among multiple climate change adaptation strategies (Tambo, 2016; Boansi et al., 2017). Being generally qualitative in nature, majority of studies conducted so far (Shiferaw et al., 2014; Thornton and Herrero, 2014; Vignola et al., 2015), have looked at barriers of adaptation without placing emphasize on its household adoption determinants. Given the fact that not all households are equally capable to adopt adaptation strategies due to variation in farming and livelihood contexts (Falco, 2014), analysing its adoption determinants is an essential precursor to deal with current and projected climate change. Bridging this research gap could provide a useful information for developing successful adaptation policies that enhance adaptive capacity and agricultural sustainability in the SSA maize system (Fisher et al., 2015).

In this study and to complement efforts made so far, we identify climate change adaptation strategies and analyse their adoption determinants and probabilities by the maize-dependent smallholders in Ethiopia.

2. Methods and materials

2.1. Study site

Our study focused on maize-dependent smallholders in Wolaita Zone (Fig. 1), Ethiopia. This area is located at an elevation range of 600–4200 m above sea level (a. s. l.). It is predominantly characterized by semi-dry to sub-humid and humd agro-ecological zones (AGRA (Aliance for a Green Revolution in Africa) (2014)). Each agro-ecological zone reflects distinct micro-climatic and socio-economic patterns. Mean annual minimum and maximum temperatures are 16 and 24 °C, respectively, whereas average annual rainfall is 900 mm (WZANRD, 2015).

Maize is the most dominant staple crop in Wolaita Zone in terms of production, occupying 42% of the land covered by grain crops (Abate et al., 2015) and providing 60% of dietary calories to rural consumers (CSA (Central Statstical Agency) (2016)). Legumes such as common

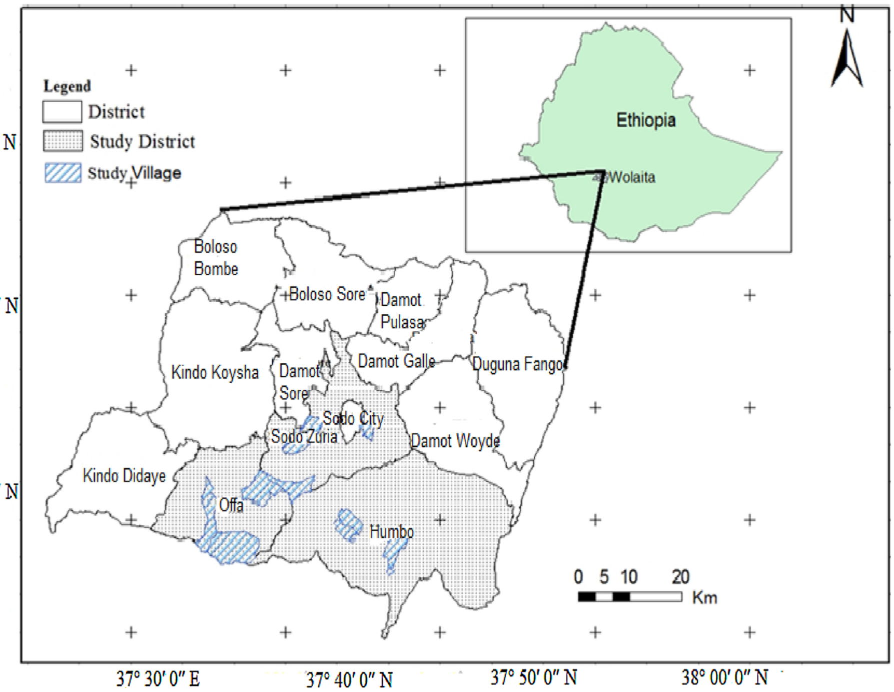

Fig. 1. Study area. Source: Reproduced with permission from WZANRD (2015).

beans (*Phaseolous vulgaris* L.) and pigeon peas (*Cajanus cajan* L.) are sometimes intercropped with maize (Asfaw et al., 2013; Falco, 2014). Soils are mainly reddish brown *Eutric nitisolos* on the steep slopes and reddish black *Humic nitisols* in the flat areas, with rainfed and a few irrigation systems (WZANRD, 2015). Such farming systems believed to produce diversified information on adoption of climate change adaptation strategies by maize-dependent smallholders.

2.2. Sampling techniques

In this study, a multi-stage sampling procedure (CSA (Central Statstical Agency) (2016)) was employed to select survey respondents for analysing adoption of climate change adaptation strategies. This sampling procedure allows to choose small sample units from larger ones while providing equal chances for all the elements to be selected (Boansi et al., 2017; Tesfaye and Seifu, 2015). First, three districts that cover diverse topographic and socio-economic conditions were selected. Then, two villages that exhibit sameness in terms of micro-climate, land use and livelihood systems were randomly selected from each district (totally six villages). Finally, a probability proportional to size sampling technique (CSA (Central Statstical Agency) (2016)), was employed for selecting 252 household heads from the study area. Additionally, 659 farm plots were selected from the study districts, using similar sampling techniques. Selected plots (between 0.12–0.2 ha each) were not spatially adjacent so that we could capture variations of plots' soil type and microclimate conditions, which will influence adoption of adaptation strategies. Household surveys were conducted from June to October 2015 through structured questionnaires, administered by trained enumerators who speak the local language and operate as a farm level agricultural extension agent in the study districts. Questionnaires informed about adaptation strategies and the biophysical features of the plots, farms and villages as well as household demographic, socio-economic and institutional conditions. Data were subjected to statistical software, satat (version 11.0) for analysis.

2.3. Analytical framework

Following Lin et al. (2005), a multivariate probit model was applied for modelling farmers' adoption decisions to interrelated climate change adaptation strategies (Lin et al., 2005). This model estimates the influence of explanatory factors on dependent variables, whilst allowing the unobserved error terms to be freely correlated. Such correlations of the error terms can be the source for complementarity (positive correlation) and substitutability (negative correlation) between different adaptation strategies (Ndiritu et al., 2014). The multivariate probit equation with latent dependent variables is described by a linear function of a set of observed households (i), plot (i), vector of explanatory variables (x_{ijm}) and normally distributed error terms (ε_{ijm})

$$y^*_{ijm} = x_{ijm}\beta_m + \varepsilon_{ijm}, \tag{1}$$

where y^*_{ijm} denotes the latent variable, which can be represented by the level of expected benefit that would be derived from adoption of an m^{th} type of adaptation strategy, and β_m is the estimate of parameter vector. An equation describing observable dichotomous choice variables is given as:

$$y_{ijm} = \begin{pmatrix} 1 & if & y^*_{ijm} > 0 \\ 0 & otherwise & \end{pmatrix}, \tag{2}$$

Where $\boldsymbol{y}_{\text{ijm}}$ indicate whether a farmer has adopted a specific strategy among m types of the climate change adaptation strategies. If the adoption of a multiple set of climate change adaptation strategies occurs at the same time, the error terms in Eq. (1) are assumed to jointly follow a multivariate normal distribution pattern with zero mean and unitary variance values (Kassie et al., 2015). This assumption means that Eq. (2) shows a multivariate probit model that represents the decision to adopt multiple climate change adaptation strategies simultaneously.

2.4. Variable descriptions and statistics

2.4.1. Dependent variables

The use of drought-resistant maize variety is one of the most-preferred climate change adaptation strategies of smallholder farmers in SSA (Falco, 2014). Mineral fertilizer use is crucial for enhancing productivity through maintaining nutrient balance in the soil, and for providing an adequate maize yield to feed growing populations. In addition, adoption of organic fertilizer derived from manure may improve soil water retention capacity and add organic matter to the soil, and hence complement mineral fertilizers (Mulwa et al., 2017).

Maize-legume cropping is defined here as rotation and/or intercropping of maize with common beans (*Phaseolus vulgaris*) and pigeon peas (*Cajanus cajan*). The latter mixed cropping help one wants to maintain soil fertility through promoting the soil nutrient recycling process (Tongruksawattana, 2014). It also decreases risks of weed, pest and disease incidents by promoting complementarity among crop species (Ndiritu et al., 2014). Intercropping legume species in between maize rows rather than within rows can provide shade from maize and thus improve legume yields (Asfaw et al., 2013).

Conservation tillage that leaves the previous year's crop residues (e.g. corn stalks, stems, leaves and legume seed pods) on the fields after harvest, increases the rate of water infiltration by reducing erosion and run-off rates (Asfaw et al., 2013), allowing early cropping with the first rains of the following planting season as a result of increased soil water availability (Kassie et al., 2015), and by increasing nutrient and organic matter contents (Wainaina et al., 2016).

SWC practices are defined as the use of physical measures such as terraces, ditches and soil bunds as well as biological measures, including grass strips and reforestation that help maintain soil fertility and conserve biodiversity by reducing surface runoff, erosion and flood (Ndiritu et al., 2014; Nhemachena et al., 2014; Tesfaye and Seifu, 2015). Hence, the adoption of SWC practices helps smallholder farmers increase agricultural productivity while building their resilience capacity in the context of climate change.

2.4.2. Explanatory variables

2.4.2.1. Natural capital. Farmers with fertile plots generally realize higher returns even without much investment in SWC practices (Boansi et al., 2017; Shiferaw et al., 2014). Hence, good soil fertility is expected to have a negative relationship with adoption of climate change adaptation strategies. Gentle slope plots are less likely to be prone to soil erosion and thus they are assumed to be negatively associated with use of SWC practices (Kassie et al., 2013) compared to steep slope plots (Wainaina et al., 2016). Besides, optimum rainfall in humid agroecological zones can stimulate weed growth and fungi development (Kassie et al., 2015), which may negatively influence the adoption of conservation tillage (Tambo, 2016). With frequent droughts and dry spells, farmers located in semi-arid agro-ecological zones are more likely to adopt drought-resistant crop varieties than farmers located in humid areas (Piya et al., 2013).

2.4.2.2. Human capital. Household education status may influence the probability of adoption of drought-resistant crop varieties (Hisali et al., 2011). Access to education promotes the farmers' ability to fully appreciate the importance of conservation tillage that maintains soil nutrient and organic matter contents. However, the relationship between age of the household head and adoption of SWC practice is often not analysed linearly (Asfaw et al., 2013; Ndiritu et al., 2014). On the one hand, age of the household head can be expressed by farm experience of the household (measured in years), which has been shown to positively influence the use of terraces, micro-dams and ditches. On the other hand, older farmers might be reluctant to adopt SWC practices once they perceive implementation costs (Shiferaw et al., 2014). Family size can be a proxy to intra-household labour supplies that positively affect the adoption of labour-intensive practices such as soil and stone bunds. Households with large and productive human capital are more likely to invest in labour-intensive crop diversification (Asfaw et al., 2013) and terracing practices (Bryan et al., 2009). Male-headed households are more likely to adopt improved maize varieties and chemical fertilizers as compared to female-headed households who have poor access to information because of cultural norms (Falco, 2014). Consequently, land ownership is often negatively affected by gender-based discriminations that favour men in many parts of SSA and everywhere in Ethiopia as women usually lack ownership rights (Wainaina et al., 2016).

2.4.2.3. Physical capital. A large landholding was expected to positively influence the adoption of climate change adaptation strategies such as conservation tillage and SWC practices. Having large landholding provides a better opportunity to diversify production (Boansi et al., 2017; Yegbemey et al., 2013), and consequently increases household income and investment in drought-resistant crop varieties and chemical fertilizers (Deressa et al., 2009; Falco, 2014). Increased livestock holding allows the use of animal manure that either supplements or complements mineral fertilizers in maintaining soil fertility (Mulwa et al., 2017). It may also be positively associated with adoption of drought-resistant maize varieties and chemical fertilizers by providing higher net income from selling animal products on the local market (Kassie et al., 2015; Wainaina et al., 2016). Increased distance from local market centres is a proxy measure to poor information access on local weather, and would thus influence adoption of adaptation strategies (Kaliba et al., 2000). Farmers living very far away from market centres often adopt maize-legume cropping and conservation tillage that require low transaction costs to implement (Tesfaye and Seifu, 2015; Wainaina et al., 2016).

2.4.2.4. Financial capital. Financial capital represents monetary sources such as credits, savings and other household income sources (Asfaw et al., 2013; Below et al., 2012; Falco, 2014). Access to microcredit services may ease farmers' cash constraints and thus positively associated with use of chemical fertilizers, high-yielding crop varieties, and/or irrigation pumps (Nhemachena et al., 2014; Wainaina et al., 2016). Household non-farm income can be positively correlated with adoption of climate change adaptation strategies. Increased household non-farm income from petty trading, woodworking and animal bartering provides farmers with additional financial capital for investing in improved crop varieties and fertilizers (Kassie et al., 2015).

2.4.2.5. Social capital. Farmers who have many contacts with local traders are more likely to have agricultural input costs and production prices on local markets and thus adopt agricultural technologies (Wainaina et al., 2016). When access to such type of information is scarce and markets are imperfect, strong social networks such as kinship promote: (1) financial transfers that help farmers overcome cash availability constraints (Asfaw et al., 2013); (2) diffusion of novel agricultural adaptation technologies and practices (Bryan et al., 2009); (3) willingness to take risks by placing trust in others and mutual relationships that helps to reduce transaction costs (Yegbemey et al., 2013); and (4) sharing of food and water between households when climate change-induced risks/problems occur (Kassie et al., 2013). Households who have poor contacts with local farmer organisations may still find information on novel agricultural technologies within their family networks (Wainaina et al., 2016).

2.4.2.6. Local institutions. Farmers in some parts of SSA are more likely to apply mineral fertilizers, chemical pesticides and improved crop varieties to increase production on rented plots than privately owned plots mainly because of low willingness to invest in labour-intensive SWC practices that have long term benefits (Simbizi et al., 2014) and high risk of eviction by landowners (Kaliba et al., 2000). Hence, plot tenure security was hypothesized to have a positive effect on adopting conservation tillage and SWC practices. Farmers' agricultural technology choices may be influenced by farmers' confidence in extension agents' capacity for promoting adaptation strategies (Bryan et al., 2009). Hence, increasing farmers confidence in extension agents is hypothesized to influence adoption of climate change adaptation positively. Active participation in farmer organisations can help farmers

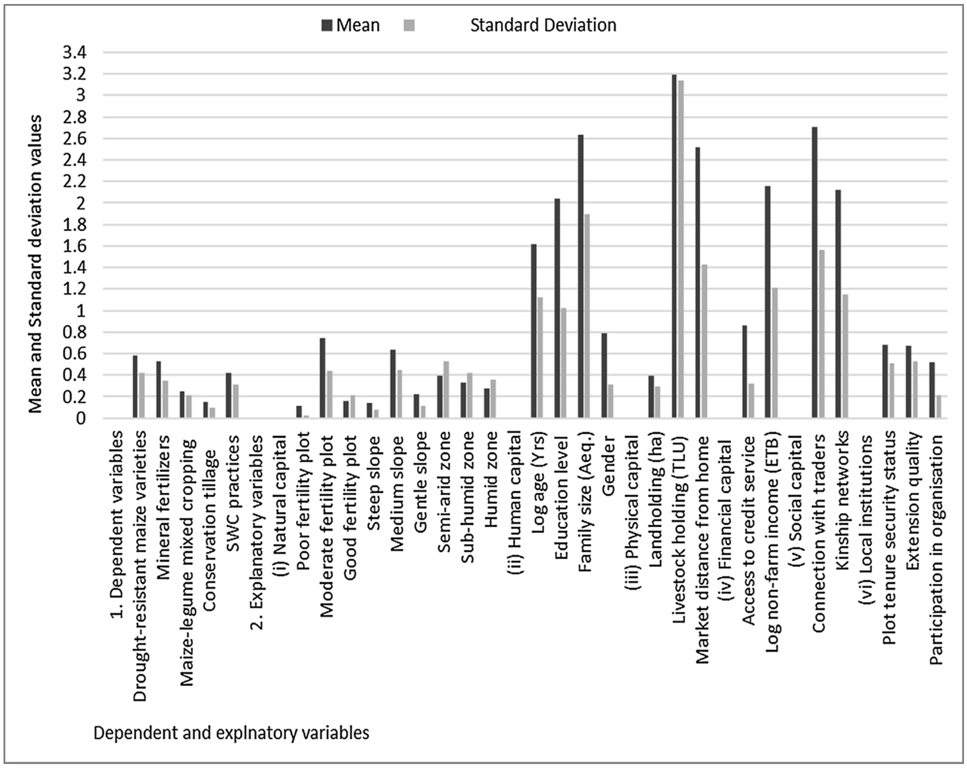

Fig. 2. Dependent and explanatory variable descriptions as well as their mean and standard deviations scores (n = 252).

Table 1
Correlation coefficient of climate change adaptation strategies (from the multivariate probit model).

Climate change adaptation strategies	Correlation coefficients	Std error
Drought-resistant maize varieties and mineral fertilizers	.0429**	0.021
Drought-resistant maize varieties and maize-legume cropping	0.568***	0.023
Drought-resistant maize varieties and conservation tillage	0.135	0.022
Drought-resistant maize varieties and SWC practices	0.325*	0.125
Mineral fertilizers and maize-legume cropping	−0.385**	0.132
Mineral fertilizers and conservation tillage	−0.102	0.012
Mineral fertilizers and SWC practices	0.529***	0.235
Maize-legume cropping and conservation tillage	0.217	0.102
Maize-legume cropping and SWC practices	0.335*	0.138
Conservation tillage and SWC practices	0.424***	0.241

Likelihood ratio test of rho12 = rho13 = rho14 = rho15 = rho23 = rho24 = rho25 = rho34 = rho35 = rho45 = 0. chi2 (5) = 79.692***. Note that ***, ** and * indicate significance at 1%, 5% and 10%, respectively.

to adopt terracing, soil bunds and micro dams that reduce nutrient depletion and surface run-off by promoting information sharing among members (Boansi et al., 2017; Falco, 2014). Household membership in local farmer organisations is hypothesized here to positively affect adoption of climate change adaptation strategies.

3. Results and discussions

3.1. Descriptive statistics

Fig. 2 shows descriptive statistics for the dependent and explanatory variables used in our analysis. Of the total households surveyed, 79% were male-headed, whereas the remaining 21% were female-headed. Household heads had a mean age of 42.62 years with an average size of 2.6 measured in adult-equivalent. Most household heads have low level of education (2 years of schooling on average). A statistically sizable proportion of households had access to credit services (86%), whereas over half of the sampled farmers are member of local farmer organisations. Most (68%) households privately owned their plots and thus manage and benefit from their lands without facing any external treats, whereas the remaining households owned it through either leasing in or sharecropping. Of the total farm plots surveyed, households adopt drought-resistant maize varieties on 58% of plots, whereas mineral fertilizers are applied to 53% of plots. On 42% of plots, households adopt SWC practices that reduce surface run-off and erosion rates. Adoption of mixed maize-legume cropping, and conservation tillage practices were employed on 25% and 15% of plots, respectively.

3.2. Econometric model outputs

Results show that in many cases, the probability of adopting a specific adaptation strategy increases among maize-dependent smallholders when they tend to use another adaptation strategy simultaneously. Such adaptation strategies are substantially (χ^2 (10) = 79; P < 0.01) interrelated to one another, implying complementarity among these strategies. This strong relationship is further supported by several significant pairwise correlation coefficients evidenced among the error terms (Table 1).

In our study, perhaps not surprisingly, the propensity of farmers to adopt drought-resistant maize variety increases with use of mineral fertilizers. Such chemical fertilizers mainly used in our study area, include Nitrogen (N) and Phosphorus (P) along with Urea (Diammonium phosphate) that enhance soil nutrient and moisture contents. Because of high population growth and associated decline in land size, farmers noted that fallowing is no longer useful to increase productivity and meet food demands. For example, in a semi-arid agro-ecology, the propensity of farmers who grow similar species of improved crop varieties within the same plot in a sequential season, are more likely to adopt mineral fertilizers. This is because the use of similar crop varieties over the same plot in a sequential growing season, degrades soil fertility and organic matter, which in turn led to decline in mean crop yields. Consequently, combing drought-resistant maize varieties along with chemical fertilizers allows farmers to increase productivity and maximize their net economic returns while dealing with climate change. Likewise, farmers who use maize-legume intercropping are more likely to simultaneously adopt conservation tillage practices during the drought period. This relationship is because promotion of low-cost conservation tillage practices such as green manure and crop residue help farmers to reduce the cost of chemical fertilizer whilst maintaining soil fertility and moisture content. This is in line with study in West African Sudan Savanna by Boansi et al. (2017) who showed positive relationships between adoption of mineral fertilizer and improved crop varieties along with use of organic manure.

In some cases, findings show that the likelihood of using mineral fertilizer significantly decreases among farmers who adopt maize-legume cropping (Table 1). Farmers are adopting the latter adaptation practices as substitutes to the former, implying that each practice can be sequentially used when one wants to maintain the soil fertility and then increase production. This negative relationship is because the probability of using mineral fertilizers significantly decrease among farmers with low-fertility plots but increase among farmers with high fertility plots. Poor soil fertility leads to lower yield and household revenue and net income. Such financial limitation due to lack access to credit might have constrained farmers from investing in mineral fertilizers and improving soil productivity. Hence, the adoption of mixed maize-legume cropping either complement or substitute the use of mineral fertilizers while reducing farmers' financial constraints. This result is consistent with findings in Kenya by Wainaina et al. (2016) who showed a negative relationship between mineral fertilizer use and maize-legume cropping in the context of dryland agriculture.

The probability of using SWC practices increases among farmers having plots with steep slopes but decreases among farmers having farm plots with gentle slopes. In Humid, high altitude and hilly parts of the study area, most farmers having farm plots with steep slopes are exposed to moving water caused by recurrent flooding that erodes the precious top layer of soil containing essential soil nutrient for crop production. In the latter slope gradient, the water itself cannot be immediately absorbed by the soil or retained by the micro topography but moves off down the slope in the form of runoff. This high rate of soil degradation and water infiltration in the steep slope was further exacerbated through clearing of vegetation for farm expansion, livestock overgrazing, burning of crop residue, deforestation and global warming. To reduce and protect from such adverse environmental change impacts, farmers are adopting SWC practices such as micro dams and terracing. Such adaptation practices allow to control and off course prevent erosion in three different but interrelated ways: by (i) protecting the surface of the soil, as far as possible, from the effects of raindrops directly striking the soil surface; secondly: (ii) trying to ensure that the maximum amount of water reaching the soil surface is absorbed by the soil; and (iii) attempting to make any water which cannot be absorbed drain off at velocities which are low enough to be non-erosive. On the other hand, farmers having plots with gentle slope in the study area are more likely to adopt drought-resistant maize than farmers having plots with steep slopes. Such gentle slopped plots are located in a semi-arid agro-ecological zone where the plots are relatively plain and subject to low soil degradation, and thus farmers rarely invest in high-cost SWC practices. These findings are consistent with previous studies in Ethiopia by Deressa et al. (2009) and Tesfaye and Seifu (2015) who revealed a statistically significant relationship between plot slope gradient and use of SWC practices.

The likelihood of using drought-resistant maize variety and mineral fertilizer significantly increase among farmers having plots with large holdings or parcel size (Table 2). Such state of plot allows farmers to diversify crops, produce higher yields, increase household income, and thereby invest in high-cost agricultural technologies. Hence, farmers use improved agricultural technologies to optimize land use, productivity and return to inputs by changing land management system. Promoting the adoption of size-neutral technologies such as novel agricultural input use system and farm machinery that substitutes the human labour, eventually allow the large farmers to make efficient use of their landholdings. These results are consistent with findings in Ghana by Tambo (2016) who revealed a positive relationship between household landholding size and drought-resistant crop variety adoption in the context small farm settings.

However, diminishing of landholding size per household in the study area is predominantly associated with land inheritance from families to offspring. This land tenure system is because old farmers have a moral obligation to provide all of their sons with some shares of their landholdings. Such obligation is reinforced by the assumption that the sons and their families would be subject to low insecure livelihoods without the land. Consequently, high rate of land fragmentation may have caused in small landholding, on average less than 0.39 ha per household head. Farmers with a small landholding are likely to use conservation tillage practices that enhance productivity and yields through reducing agricultural input cost and increasing net income. These negative associations between land size and conservation tillage adoption are in line with studies by Kassie et al. (2015) in Ethiopia and Wainaina et al. (2016) in Kenya.

Farmers who have secured plot tenure status are more likely to use soil bund preparation and terracing significantly increases than farmers who lack plot tenure security (Table 2). Such type of positive relationship may be explained in three mechanisms: farmers having (i) right to use and benefit from the plot in the long run, are likely to use productivity-enhancing practices and at the same time reducing climate risks; (ii) secured plot tenure but farming in highly degraded and fragile areas, tend to install ditches and stone bunds to increase the productivity of plot while improving its tendency to be leased out quickly and at higher cost; and (iii) guaranteed plot holding title, e.g. through certifications, are likely to use the plot as collateral for accessing cash credits and investing in natural resource management. On the other hand, farmers having poor tenure security are more likely to use high-cost agricultural technologies such as chemical fertilizers and drought-resistant maize varieties. This negative relationship is because farmers particularly give higher emphasize for maximizing only economic returns, disregarding environmental sustainability on rented plots due to fear of expulsion by the owner. The latter finding corroborates those of a study by Kassie et al. (2013) in Tanzania that revealed a significant correlation between plot tenure security and drought-resistant crop variety adoption.

The likelihood of adopting SWC practices, drought-resistant varieties and mixed maize-legume cropping significantly increases among young, highly-educated and male-headed households (Table 2). This relationship is because the latter categories of households are less risk-averse and have better access to information on sustainable intensification practices that increase productivity and yields. Old and female-headed households are more likely to use low-cost agronomic practices such as conservation tillage and mixed-maize legume cropping practices. These groups of farmers are often constrained with adequate finance to invest in income-generating activities due to poverty and other socio-cultural barriers. Hence, they tend to use less productive agricultural practices, but still adopt climate-smart agricultural strategies. These results are consistent with earlier works by Asfaw et al. (2013) in Malawi and Kassie et al. (2015) in Kenya who revealed a significant relationship between household head age and education with use of improved crop varieties as well as SWC practices.

The probability of adopting drought-resistant maize varieties, mineral fertilizers, and SWC practices significantly increases among farmers having access to microcredit services (Table 2). Access to microcredit services facilitates financial provisions based on the farmers'

Table 2
Multivariate probit regression model outputs.

Explanatory variables	Drought-resistant maize varieties Coef. Std error	Mineral fertilizers Coef. Std error	Maize-legume cropping Coef. Std error	Conservation tillage Coef. Std error	SWC practices Coef. Std error
Natural Capital					
Poor fertility plot	0.123 (0.169	−0.585 (0.392) ***	0.363 (0.255) *	−0.055 (0.153)	0.152 (0.065)
Moderate fertility plot	−0.132 (0.235)	0.240 (0.191)	−0.022 (0.116) *	0.179 (0.192)	0.452 (0.331) ***
Steep slope	−0.413 (0.299) ***	−0.325 (0.216) *	−0.152 (0.099)	−0.214 (0.121)	0.465 (0.234) ***
Medium slope	0.213 (0.288)	0.023 (0.006)	0.458 (0.211) **	0.032 (0.023)	0.256 (0.288)
Semi-arid zone	0.606 (0.409) ***	0.061 (0.013)	0.167 (0.2046)	0.267 (0.105)	0.0852 (0.106)
Sub-humid zone	−0.114 (0.240)	−0.193 (0.206)	0.071 (0.102)	0.235 (0.211)	−0.556 (0.301) ***
Human Capital					
Age (Yrs.)	−0.425 (0.258) ***	0.209 (0.086)	0.136 (0.031)	0.516 (0.365) ***	0.026 (0.009)
Education level	0.457 (0.286) ***	0.234 (0.215)	0.019 (0.024)	0.029 (0.023)	0.435 (0.265) ***
Family size (Aeq)	0.019 (0.008)	0.200 (0.109)	0.326 (0.279) **	0.065 (0.007)	0.215 (0.126)
Gender	0.452 (0.213) ***	0.356 (0.221) **	−0.192 (0.206)	−0.435 (0.239) **	0.215 (0.126)
Physical capital					
Landholdings (ha)	0.756 (0.399) ***	0.653 (0.344) ***	−0.425 (0.392) ***	0.052 (0.214)	0.003 (0.021)
Livestock holding (TLU)	0.425 (0.232) **	0.325 (0.231) *	0.223 (0.055)	0.097 (0.033)	0.015 (0.050)
Market distance (hrs)	−0.120 (0.101)	−0.086 (0.185)	0.118 (0.294)	0.399 (0.287) **	0.052 (0.152)
Financial capital					
Access to credit services	0.406 (0.228) **	0.324 (0.206) *	−0.036 (0.213)	−0.166 (0.204)	0.525 (0.304) ***
Non-farm income	0.356 (0.290) **	0.372 (0.278) *	−0.018 (0.164)	0.161 (0.199)	0.314 (0.266) **
Social capital					
Connection with traders	0.384 (0.213) **	0.245 (0.252)	0.432 (0.255) ***	0.485 (0.264) ***	0.396 (0.265) **
Number of relatives	0.606 (0.409) ***	0.061 (0.013)	0.167 (0.204)	0.267 (0.105)	0.0852 (0.106)
Local institutions					
Plot tenure security status	−0.085 (0.195)	−0.389 (0.225) **	0.210 (0.210)	0.224 (0.214)	0.421 (0.354) ***
Extension quality	0.456 (0.310) ***	0.342 (0.298) *	0.328 (0.234) *	0.391 (0.197) **	0.324 (0.256) **
Membership in farmer organisations	0.384 (0.213) **	0.325 (0.252) *	0.432 (0.255) ***	0.331 (0.199) *	0.314 (0.266) **
Model summary					
No of observations		252			
Wald chi-square (95%)		79.692*** -			
Log likelihood		577.968			

Note ***, ** and * indicate significance at 1%, 5% and 10%, respectively.

past loan repayment that either allows or denies them to receive additional credits for investing in ditches and micro dams. Such financial assets are leveraged by microcredit institutions that promote the use of diversified income-generating sources whilst enhancing their capacity to purchase improved agricultural technologies. For example, Omo Microfinance Institution found in the study area, offers both saving and credit services that allow farmers to invest in high-cost agricultural inputs such as improved maize varieties and fertilizers. This type of institutional can help people self-insure and pursue more riskier and potentially more profitable livelihood activities. This finding is also in line with the study in Malawi by Mulwa et al. (2017) and in Nepal by Piya et al. (2013) who showed a positive and significant relationship between access to microcredit services and use of improved crop varieties.

Farmers' having confidence in extension agents for promoting climate change adaptation are more likely to adopt drought-resistant maize varieties and conservation tillage practices. This is because increasing confidence in extension agents smooths sharing of information, communication and cooperation among themselves. Such confidence enhances the capacity of farmers, extension workers and private individuals in using adaptation strategies by providing adequate knowledge and experience related to adverse climate change impacts. This positive and significant relationship is consistent with earlier work in Malwai by Mulwa et al. (2017) and Ethiopia by Shiferaw et al. (2014) who revealed a positive relationship between extension quality and adoption of SWC practices.

The likelihood of adopting drought-resistant maize varieties, mineral fertilizers and SWC practices significantly increase among farmers having many relatives but decrease with farmers who have a few relatives inside and/or outside a specific community (Table 2). Large relative networks ease the spread of climate change adaptation information flow through promoting mutual interaction, feeling of closeness and trust among farming communities. Such strong social ties provide incentives for farmer to take coping action against crop failure and property loss caused by extreme events, such as floods by providing self-insurance in the form of labour or finance. These results are in line with previous studies that revealed positive and significant effect of social connection with friends and families on agricultural technology adoption (Falco, 2014; Kassie et al., 2013). In addition, households who participate in local organisations are more likely to adopt drought-resistant maize varieties and mineral fertilizers than farmers that do not participate in local organisations (Table 2). Such type of membership significantly increases adoption of maize-legume cropping and SWC practices by improving access to information on these strategies. This finding fits the study in Northern Ethiopia by Falco and Bulte (2011) who showed household membership within a specific local organisation significantly increases adoption of improved crop varieties and SWC practices among small farming communities.

4. Conclusions and implications

Our paper aimed at analysing interactions between adoption of different climate change adaptation strategies among maize-dependent smallholders, through a multivariate probit model. The null hypothesis that adoptions of different climate change adaptation strategies among farmers do not interrelate, was rejected (Table 1). We thus tested the alternate hypothesis of interrelationship between the adoption of climate change adaptation strategies by farmers, which justified a multivariate probit model use. Results showed that in vast majority cases the probability of adopting a specific adaptation strategy significantly increase with the adoption of other type of adaptation strategies, suggesting complementarities among these strategies. In some cases, the likelihood of using a specific adaptation strategy significantly decrease with the adoption of another adaptation strategy, indicating substitutability effects. Hence, our findings support the hypothesize that adoption of different climate change adaptation strategies by maize-dependent smallholders are interrelated to one another. This conclusion implies that both productivity and economic outcomes of climate change adaptation strategies are conditional on the adoption of other adaptation strategies.

Our findings suggest that a program or policy that promotes adoption of drought-resistant maize varieties and chemical fertilizers would simultaneously encourage use of SWC practices and conservation tillage that help conserve soil structure, humidity and nutrients. These combined agronomic and natural resource management practices can be promoted by providing better extension and advisor services that emphasize the complementarity among these practices. Extension organisations should focus on finding ways to provide low-cost organic manure, crop residue and mixed maize-legume cropping along with high-cost seed and chemical fertilizer as packages to simultaneously or sequentially achieve both productivity or environmental outcomes.

Our study also aimed at analysing the adoption determinants of climate change adaptation that could help design dissemination strategies. It was hypothesized that adoption of climate change adaptation strategies is influenced by household age level, household gender status, household education level, farmers' confidence in extension agents, household number of connection with friends and families as well as their membership in local farmer organisations. Findings showed that the likelihood of adopting SWC practices, drought-resistant maize varieties and chemical fertilizers significantly increases among young, male-headed and highly-educated households as well as farmers with confidence in extension agents for promoting adaptation strategies. The probability of adopting conservation tillage and maize-legume cropping practices significantly increases among farmers' having large family ties and relative networks in and outside a specific community as well as membership within a specific local organisation. Hence, our findings support the hypothesis that adoption of climate change adaptation strategies is influenced by household education, confidence in extension agents, number of family and relative ties or networks as well as membership in local farmer organisations. These findings have several important policy implications for climate change risk management and adaptation planning in the study area.

Our results suggest there is need for policies promoting (improved access to and quality of) formal education as a way to increase farmers' capacity in processing information related to multiple climate change adaptation strategies. The significant effect of social network indicates that policy makers should focus on strengthening social ties that enhance connections among families and friends within and outside community by enhancing their capacity to organise, coordinate and communicate in using diversity of SWC practices. Improving the dissemination of information in combining conservation tillage with drought-resistant maize varieties through family networks would enable farmers to find stable agricultural input-output market outlets and credit services. Also, particular attention should be given to strengthen household participation in local organisations through developing effective platform that allow farmers to cooperate and share experience on climate change adaptation strategies. Such participation of farmers in local organisations do not only promote adoption of climate change strategies by improving household access to information on these strategies, but also facilitate provision of external interventions through extra-local organisations such as public extension agencies, and official development and non-governmental organisations.

Further research may be needed to elucidate how diverse types of local farmer organisations address vulnerability to climate change, mediate individual and collective responses to this change, and deliver external technological and financial resources to reduce these impacts through fostering linkages with other types of organisations.

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References

Abate, T., Shiferaw, B., Menkir, A., Wegary, D., Kebede, Y., Tesfaye, K., Keno, T., 2015. Factors that transformed maize productivity in Ethiopia. Food Secur. 7 (5), 965–981. https://doi.org/10.1007/s12571-015-0488-z.

Adimassu, Z., Kessler, A., Stroosnijder, L., 2014. Farmers' strategies to perceived trends of rainfall and crop productivity in the Central Rift Valley of Ethiopia. Environ. Dev. 11, 123–140. https://doi.org/10.1016/j.envdev.2014.04.004.

AGRA (Aliance for a Green Revolution in Africa), 2014. African Agriculture Status Report: Climate Chnage and Smallholder Agriculture in Sub-saharan Africa. Nirobi, Kenya.

Asfaw, S., Mccarty, N., Lipper, L., Arslan, A., 2013. Adaptation to climate change and food security in Africa. In 4th International Conference of the African Asssociation of Agricultural Economics.

Bedeke, S.B., Beyene, F., 2013. Small-scale irrigation and household income linkage: evidence from Deder district, Ethiopia. Afr. J. Agric. Res. 8 (34), 4441–4451. https://doi.org/10.5897/AJAR12.1793.

Below, T.B., Mutabazi, K.D., Kirschke, D., Franke, C., Sieber, S., Siebert, R., Tscherning, K., 2012. Can farmers' adaptation to climate change be explained by socio-economic household-level variables? Glob. Environ. Chang. Part A 22 (1), 223–235. https://doi.org/10.1016/j.gloenvcha.2011.11.012.

Boansi, D., Tambo, J.A., Müller, M., 2017. Analysis of farmers' adaptation to weather extremes in West African Sudan Savanna. Weather Clim. Extrem. 16, 1–13. https://doi.org/10.1016/j.wace.2017.03.001.

Bryan, E., Deressa, T.T., Gbetibouo, G.A., Ringler, C., 2009. Adaptation to climate change in Ethiopia and South Africa: options and constraints. Environ. Sci. Policy 12 (4), 413–426. https://doi.org/10.1016/j.envsci.2008.11.002.

Conway, D., Schipper, L.F., 2011. Adaptation to climate change in Africa: challenges and opportunities identified from Ethiopia. Glob. Environ. Chang. Part A 21 (1), 227–237. https://doi.org/10.1016/j.gloenvcha.2010.07.013.

CSA (Central Statstical Agency), 2016. Report on Area and Production of Major Crops 584 The Federal Democratic Republic of Ethiopia. Statistical Bulletin, Addis Ababa.

Davis, K.E., 2009. Agriculture and Climate Change: an Agenda for Negotiation in Copenhagen: the Important Role of Extension Systems. Denmark.

Deressa, T.T., Hassan, R.M., Ringler, C., Alemu, T., Yesuf, M., 2009. Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia. Glob. Environ. Chang. Part A 19 (2), 248–255. https://doi.org/10.1016/j.gloenvcha.2009.01.002.

Falco, S., 2014. Adaptation to climate change in Sub-Saharan agriculture: assessing the evidence and rethinking the drivers. Eur. Rev. Agric. Econ. 41 (3), 405–430. https://doi.org/10.1093/erae/jbu014.

Falco, S., Bulte, E., 2011. A dark side of social capital? kinship, consumption, and savings. J. Dev. Stud. 47 (8), 1128–1151. https://doi.org/10.1080/00220388.2010.514328.

Feder, G., Just, R., Silberman, D., 1981. Adoption of agricultural innovations in developing countries: a survey. Econ. Dev. Cult. Change 33 (2), 255–298. https://doi.org/10.1086/451461.

Fisher, M., Abate, T., Lunduka, R.W., Asnake, W., Alemayehu, Y., Madulu, R.B., 2015. Drought tolerant maize for farmer adaptation to drought in sub-Saharan Africa: Determinants of adoption in eastern and southern Africa. Clim. Change 133 (2), 283–299. https://doi.org/10.1007/s10584-015-1459-2.

Hisali, E., Birungi, P., Buyinza, F., 2011. Adaptation to climate change in Uganda: evidence from micro level data. Glob. Environ. Chang. Part A 21 (4), 1245–1261. https://doi.org/10.1016/j.gloenvcha.2011.07.005.

Kaliba, A.R., Verkuijl, H., Mwangi, W., 2000. Factors affecting adoption of improved maize seed and use of inorganic fertiliser for maize production in the intermediate and lowlland zone of Tanzania. J. Agric. Econ. 48 (1), 1–12. https://doi.org/10.1111/j.1477-9552.1997.tb01126.x.

Kassie, M., Jaleta, M., Shiferaw, B., Mmbando, F., Mekuria, M., 2013. Adoption of interrelated sustainable agricultural practices in smallholder systems: evidence from rural Tanzania. Technol. Forecast. Soc. Change 80 (3), 525–540. https://doi.org/10.1016/j.techfore.2012.08.007.

Kassie, M., Teklewold, H., Jaleta, M., 2015. 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.

Lin, C.J., Jensen, K.L., Yen, S.T., 2005. Awareness of Foodborne Pathogens Among US Consumers 16. pp. 401–412. https://doi.org/10.1016/j.foodqual.2004.07.001.

Lobell, B., Bänziger, M., Magorokosho, C., Vivek, Bindiganavile, 2011. Nonlinear heat effects on African maize as evidenced by historical yield trials. Nat. Clim. Chang. 1 (1), 42–45. https://doi.org/10.1038/nclimate1043.

Mulwa, C., Marenya, P., Bahadur, D., Kassie, M., 2017. Response to climate risks among smallholder farmers in Malawi: a multivariate probit assessment of the role of information, household demographics and farm characteristics. Clim. Risk Manag. 16, 208–221. https://doi.org/10.1016/j.crm.2017.01.002.

Ndiritu, S.W., Kassie, M., Shiferaw, B., 2014. Are there systematic gender differences in the adoption of sustainable agricultural intensification practices? Evidence from Kenya. Food Policy 49 (1), 117–127. https://doi.org/10.1016/j.foodpol.2014.06.010.

Nhemachena, C., Hassan, R.M., Chakawizira, J., 2014. Analysis of determininats of farm-level adaptation measures to climate change in Southern Africa. Journal of Development and Agricultural Economic 6 (5), 232–241 http:// doi.org/10.5897/JDAE12.0441.

Piya, L., Maharjan, K.L., Joshi, N.P., 2013. Determinants of adaptation practices to climate change by Chepang households in the rural Mid-Hills of Nepal. Reg. Environ. Change 13 (2), 437–447. https://doi.org/10.1007/s10113-012-0359-5.

Shiferaw, B., Tesfaye, K., Kassie, M., Abate, T., Prasanna, B.M., Menkir, A., 2014. Managing vulnerability to drought and enhancing livelihood resilience in sub-Saharan Africa: technological, institutional and policy options. Weather Clim. Extrem. 3, 67–79. https://doi.org/10.1016/j.wace.2014.04.004.

Simbizi, M.C.D., Bennett, R.M., Zevenbergen, J., 2014. Land tenure security: revisiting and refining the concept for Sub-Saharan Africa's rural poor. Land use policy 36, 231–238. https://doi.org/10.1016/j.landusepol.2013.08.006.

Tambo, J.A., 2016. Adaptation and resilience to climate change and variability in north-east Ghana. Int. J. Disaster Risk Reduct. 17, 85–94. https://doi.org/10.1016/j.ijdrr.2016.04.005.

Tesfaye, M., Seifu, L., 2015. Climate change perception and choice of adaptation strategies: an empirical evidence from smallholder farmers in east Ethiopia. Int. J. Clim. Chang. Strateg. Manag. 8 (2), 253–270. https://doi.org/10.1108/IJCCSM-01-2014-0017. Downloaded.

Thornton, K., Herrero, M., 2014. Climate Change Adaptation in Mixed Crop-livestock Systems in Developing Countries. Nairobi, Kenya. https://doi.org/10.1002/jssc.201300750.

Tongruksawattana, S., 2014. Climate Shocks and Choice of Adaptation Strategy for Kenyan Maize-legume Farmers: Insights From Poverty, Food Security and Gender Perspectives. Socioeconomics Program Working Paper No. 11, Nairobi, Kenya.

Vignola, R., Alice, C., Bautista-solis, P., Avelino, J., Rapidel, B., Donatti, C., Martinez, R., 2015. Agriculture, Ecosystems and Environment Ecosystem-based adaptation for smallholder farmers : definitions, opportunities and constraints. Agric. Ecosyst. Environ. 211, 126–132. https://doi.org/10.1016/j.agee.2015.05.013.

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

World Bank, 2008. Ethiopia: a Country Study on the Economic Impacts of Climate Change, World Bank Report, Adddis Ababa.

WZANRD (Wolaita Zone Agriculture and Natural Resource Department) (2015). Description about Wolaita Zone, Wolaita Sodo, Ethiopia.

Yegbemey, R.N., Yabi, J.A., Tovignan, S.D., Gantoli, G., Haroll Kokoye, S.E., 2013. Farmers' decisions to adapt to climate change under various property rights: a case study of maize farming in northern Benin (West Africa). Land use policy 34, 168–175. https://doi.org/10.1016/j.landusepol.2013.03.001.

Yu, Li., Hurley, T., Kliebenstein, J., Orazem, P., 2008. Testing for Complementarity and Substitutability Among Multiple Technologies: the Case of U.S. Hog Farms (No. 08026). Iowa.