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CLIMATE RESEARCH
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Perception of and response to climate change by maize-dependent smallholders

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ABSTRACT: Smallholder crop producers in sub-Saharan Africa are adversely affected by climate change because of their reliance on rain for crop production. Promoting adaptation interventions at local scale is unlikely to be effective without understanding farmers' views on climate change. Our study analyzes climate change perceptions and responses by maize-dependent smallholders in Ethiopia. Household-level data on farmers' climate change perceptions and adaptation strategies were collected. In addition, meteorological data were obtained from local weather stations for the period 1985–2015. Descriptive statistics, standard rainfall anomalies, thematic content methods and binary logistic models were used to analyze the relationship between climate change perceptions and adaptations. Findings show that nearly all farmers perceived climate change through increased hot and warm days and nights as well as decreased precipitation volumes. Results indicate that farmers perceive shortened seasonal rainfall duration in terms of both late start and early end. Farmers employ a range of strategies, notably cropping date adjustment, improved crop variety use, crop diversification, agroforestry practices and seasonal migration to adapt to climate change. Farmers' adaptation decisions were mainly associated with their climate change perceptions as well as socio-economic factors such as education level and farm experience. It is, therefore, suggested that recognizing farmers' knowledge and experience on climate change would help develop context-specific, flexible adaptation strategies that better build resilience capacity.

KEY WORDS: Adaptation strategies · Observed climate data · Crop yield · Resilience · Seasonal rainfall · Africa

1. INTRODUCTION

Rapidly growing global population and changing diets are driving up the demand for food. Climate change will lead to food shortage by adversely affecting crop and livestock systems (IPCC 2007, Kotir 2011, Di Falco 2014). Communities in sub-Saharan Africa (SSA) that produce weather-sensitive cereal crops by relying on rain-fed and/or poor irrigation systems (Di Falco 2014, Fisher et al. 2015) and that have a weak adaptive capacity because of poverty (Kotir 2011, Simelton et al. 2011) may be hit by climate change harder than other communities in SSA with better irrigation systems. In most parts of SSA and everywhere in Ethiopia, adverse climate change impacts will be severe on smallholder maize *Zea mays* L. farmers that depend on uneven precipitation patterns (Erenstein et al. 2011, AGRA 2014, Sutcliffe et al. 2016). Today, most SSA farmers produce maize for household consumption and sell the surplus at local markets (Adimassu et al. 2014). However, increased temperature along with erratic precipitation, and re-

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current drought and flood events, all resulting from global warming, may lead to a sharp maize yield decline and acute food insecurity (Sutcliffe et al. 2016).

In response to adverse climate change impacts, efforts to build farmers' adaptive and resilience capacity have become a top agricultural development priority in the SSA region. Demand for and investments in climate change adaptation programmes and projects are increasing across SSA (Cairns et al. 2013, AGRA 2014). Climate scientists are responding by providing information on past, current and future scenarios using models that help to visualize and simulate climate change (Boko et al. 2007). Although models are useful for anticipating effective mitigation (Fisher et al. 2015) and potential adaptation (Crane et al. 2011) strategies in SSA, they may not explicitly reproduce or simulate localized, complex climate patterns that interact with small farming and livelihood systems (Lobell et al. 2011). This is, in part, due to the limitations related to its computing power at much finer resolution (Cairns et al. 2013), the availability of detailed local weather observations (Simane et al. 2016) and scientific understanding of how local climate works (Simelton et al. 2011). For example, some studies that model climate risk mitigation frequently describe seasonal precipitation change as erratic by measuring only the mean annual amount of the change without recognizing the duration, intensity and frequency that influence this change (Mertz et al. 2009, Gioli et al. 2014, Boansi et al. 2017). Such limitations are especially pronounced in most parts of Ethiopia, where only few weather stations are available to provide adequate microclimate data for analyzing complex interactions among diverse physical features such as topography, soil type and farm condition that vary even over a single kilometre (Mertz et al. 2009, Cairns et al. 2013, Simane et al. 2016). In these contexts, a socio-cognitive approach (Kearney 1994) that combines a network of physical climate patterns with local people's views and experiences on these patterns may be useful for understanding a complex ecological and socio-economic heterogeneity that may not be covered by models (Grothmann & Patt 2005, Woods et al. 2017).

Socio-cognitive approaches have been widely used in studies that assess agricultural technology adoption (Straub 2009, Barham et al. 2017), rural health promotion (Lent et al. 2000, Andrews et al. 2013) and climate risk communication (Roncoli et al. 2009, Elum et al. 2017). Such approaches analyze farmers' climate change awareness, attitude and perception that play an important role in decision making and behavioural change (Elum et al. 2017). Studies of agricultural extension service users and non-users found no difference in awareness of and attitude towards climate change but did reveal significant differences in perception (Adimassu et al. 2014, Elum et al. 2017, Woods et al. 2017). Farmers' climate change perception is the main motivator for their adaptation (Di Falco 2014, Ayal & Filho 2017). However, some studies in SSA show that perceptions are likely to be misinterpreted and wrongly recalled because farmers may (1) fail to discriminate complex physical climate processes from their impacts because of poor information access and low educational level (Gioli et al. 2014); (2) only recall short-term weather variability events and have a limited tendency to think about long-term climate change risks in a specific range of farming and livelihood systems (Mertz et al. 2009); and (3) be influenced by traditional views, values and religious backgrounds that shape their belief on climate change and its causes (Niles & Mueller 2016). Such socio-psychological biases may contradict scientific climate observations and analysis and consequently complicate adaptation decisions (Mulenga et al. 2016).

Despite some shortcomings, farmers' perceptions indicate long-term knowledge on climate change gained through repeated personal experience and social communication (Simelton et al. 2011, Sutcliffe et al. 2016). Reported farmers' perception resulting from mentally constructed and shared experiences (Grothmann & Patt 2005) revealed that farmers acknowledge climate change vulnerability (Oppenheimer et al. 2014). In addition, farmers perceive climate change on a specific local scale where their knowledge reflects subjective, intangible aspects of local-scale weather changes and their impacts (Woods et al. 2017). For example, farmers' perception of intra-seasonal rainfall changes—such as its intensity, which affects planting regime (Adimassu et al. 2014) and its distribution, as well as periodicity, which influences tillage, irrigation and weeding systems within cropping seasons (Gioli et al. 2014)—indicates the impact that it would have on a farming system (Yaro 2013). Hence, farmers' perception provides in-depth information on adverse climate change impacts and vulnerability (Ayanlade et al. 2017) as well as on several response strategies that influence bottom-up agricultural development plans (Simelton et al. 2011, Below et al. 2015) and adaptation policy decisions (Mertz et al. 2009, Di Falco 2014).

Adaptation is how climate change perceptions translate into the agricultural production decision-making process. Farmers who perceive climate change are likely to implement a variety of crop management practices (i.e. cropping calendar adjustment, improved crop varietal selection), farm practices (i.e. rainwater harvesting and tree planting) and livelihood diversification strategies (i.e. off-farm activities and seasonal migration) that help to respond to its adverse impacts by enhancing their adaptive capacity (Hisali et al. 2011, Kotir 2011, Ayanlade et al. 2017). In addition, farmers' climate change perception may help to build resilience strategies that address complex institutional and market challenges such as poor access to agricultural extension and microcredit services beyond climate (Mertz et al. 2009). Misconceptions about climate change may lead to an inappropriate adaptation that results in poor productivity and increased vulnerability (Woods et al. 2017) and in avoidance or denial of actual threat (Grothmann & Patt 2005). Hence, understanding farmers' perception of climate change allows development agencies to combine several farm and livelihood management strategies (Adimassu et al. 2014) and helps policy makers to develop successful adaptation priorities (Gioli et al. 2014).

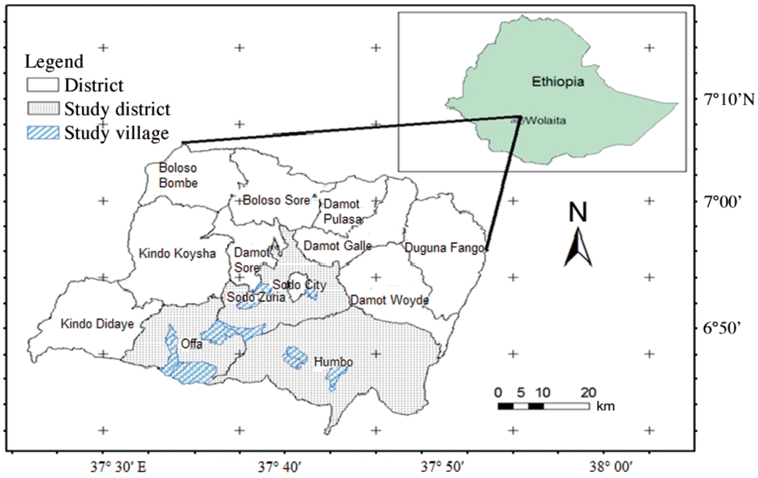

Fig. 1. Study area. Source: ANRD (2015)

Climate adaptation literature review shows that more attention has been paid to examining expert awarenesses and beliefs on climate change impacts but less to farmers' perception (Mertz et al. 2009). As a result, farmers' knowledge on climate change impact and vulnerability has been marginalized in both local and global environmental risk assessments (Cairns et al. 2013, Fisher et al. 2015) and climate science policy debates (Kotir 2011, Shiferaw et al. 2014). Although studies that evaluate climate change adaptation strategies are flourishing in several developing countries (Marin 2010, Gioli et al. 2014, Nhemachena et al. 2014, Sutcliffe et al. 2016), the association between farmers' climate change perception and their response to this change in SSA remains unclear. Hence, the present study aims to analyze how smallholders in Ethiopia perceive climate change and respond to it by implementing a variety of strategies.

2. METHODS

2.1. Study site

Our study was conducted on maize-dependent smallholders in Wolaita Zone, Ethiopia (Fig. 1), where cereal crop production is predominantly rain-fed. This zone is located between 6° 50′ 0″ N and 37° 45′ 0″ E, with diverse agroecology and socio-economic systems. Rainfall distribution follows a bimodal seasonal pattern (ANRD 2015). The short rainy season extends from March to May, whereas the long rainy season covers the months of June to September. The rainy season is interrupted by a short-spell dry season, which usually occurs between late May and early June (CSA 2016). However, increased rainfall variability and drought stress conditions have severely affected smallholder farmers that rely on rain-fed production systems. Average human population density in Wolaita Zone is 380 households km^{-2}, as opposed to the average population density of 68 households km^{-2} in the country (CSA 2014). High population pressure has resulted in massive land degradation. Most smallholders on average own less than 0.5 ha of land, which is inherited along patriarchal lines (Le Gal & Molinier 2006). Farmers dedicate a large part of their land to rain-fed maize cultivation, which is extremely sensitive to, and adversely affected by, climate change (Cairns et al. 2013). Extreme climate events such as drought, frequent erosion and flood have resulted in rapid soil degradations as well as a sharp decline in maize yield leading to food insecurity. We focused our study on only 3 districts, namely Humbo, Offa and Sodo Zuria, that largely exhibit semi-arid, sub-humid and humid agroecological zones, respectively (Table 1).

In this study, we hypothesized that farmers perceive both past and present climate changes. We further hypothesized that farmers who perceive climate change respond to this change by implementing different strategies.

2.2. Household-level data

Our study employed semi-structured interviews to understand farmers' (1) perception of climate change

Table 1. Major biophysical and socio-economic features of the study districts. Source: ANRD (2015). a.s.l.: above mean sea level

Major feature	Study district Humbo	 Offa	 Sodo Zuria
Biophysical			
Elevation (m a.s.l.)	500–1900	750–2100	1400–2350
Major agroecological zone	Semi-arid	Sub-humid	Humid
Mean annual minimum temperature (°C)	20	18	18
Mean annual maximum temperature (°C)	35	30	25
Average annual rainfall (mm) during the short rainy season	200	500	1200
Average annual rainfall (mm) during the long rainy season	800	1000	1300
Major soil characteristics	Eutric nitisols (red brown with poor organic matter content)	Humic nitisols (red black with poor moisture and nutrient contents)	Eutric nitisols
Nearest weather station	Tebela	Gasuba	Boditi
Weather station elevation (m a.s.l.)	1424	1600	1490
Socio-economic			
Population density (households km^{-2})	283	304	417.6
Average land size per household (ha)	0.32	0.23	0.26
Distance from zonal city Sodo (km)	18	25	5
Major crops	Maize and tubers	Maize and vegetables	Maize and fruits
Adult literacy rate (%)	15	18	21
Average family size	4.2	5.2	4

over the past 2 decades (1995–2015) and (2) strategies to respond to this change. A 2-stage sampling technique (Aliaga & Ren 2006) that helps to select small samples from large geographic areas by balancing precision and cost was employed. First, 2 villages were purposively selected from each study district (6 villages) based on the extent of climate risk exposure, proportion of maize producers and degree of irrigation use. Selected villages were homogeneous in terms of climate, farming and livelihood systems. Next, complete household head lists were obtained from the study village officers that operated at the local level as a sampling frame. Sample size was determined using Yamane's (1965) formula: $n = N/(1 + N\varepsilon^2)$, where n is the sample size, N is the total household number and ε is the degree of precision (0.05). Hence, a probability sampling technique that provides a sample size proportional to the entire population (Aliaga & Ren 2006) was used to select 270 household heads. Interviews were conducted in the period March to June 2015 using both open- and close-ended questions to explore detailed knowledge and experience on climate change. Care was taken to interview household heads who have been farming for longer than 20 yr. Dichotomous (yes/no) interview schedules that ensure consistency of the response by providing direct and easy questions to respondents (Menapace et al. 2014) were developed to evaluate farmers' agreement level on whether temperature as well as rainfall are increasing, decreasing or remaining the same and on whether seasonal rainfall variability patterns have become advanced (i.e. starting late and ending early, unpredictable or regular). These interviews were followed by further questions on whether farmers who perceive several risks of climate change believe it is occurring as well as being caused by human actions. These household-level data were analyzed through descriptive statistics such as frequencies and percentages, tested with chi-square (χ^2) and subsequently presented in graph and tabular forms.

In addition, a binary logistic model was employed to estimate the effect of farmers' climate change perception on their adaptation decision. It predicts the binary relationship between climate change adaptation decision and perceptions of and beliefs on this change, along with a set of other explanatory socio-economic variables such as household access to local weather information, educational level, farm experience, farm size and gender. This regression model has been widely used in studies that focus on climate resilience (Brooks et al. 2005, Piya et al. 2013, Hoang et al. 2014) and agricultural technology adoption (Hassan & Nemachena 2008, Erenstein et al. 2011, Below et al. 2012). In this model, the dependent variable for the outcome equation has 2 choices, i.e. whether a farmer is undertaking a climate change adaptation decision (with value of 1) or not (with value of 0). Hence, we assume that farm households will adapt to climate change only if they perceive its risks. Farmers who have several years of farming experience are more likely to adapt to climate change. Studies have also indicated that household years of farming experience have a positive effect on climate change adaptation decision (Hisali et al. 2011, Gioli et al. 2014). Education increases the household decision-making capacity against climate change by creating awareness.

Household educational level may be positively related to farmers' climate change adaptation decision (Nhemachena et al. 2014). Access to information on local weather conditions through extension agents or mass media (radio or television) may create awareness and knowledge in responding to climate change (Mertz et al. 2009). Detailed descriptions of the hypothetical relationships between explanatory variables and climate change adaptation decisions are also described in studies by Deressa et al. (2009), Hisali et al. (2011) and Di Falco (2014). Following Greene (2012), the binary logistic model for n independent or explanatory variables (X_1, X_2, X_3,…$X\hat{n}$) that influence the climate change adaptation decision is given by $P(X) = \beta_0 + \sum_{i=1}^{n} \beta_i X_i$, where $P(X)$ is the log of the odds ratio for farmers having characteristics i versus not having i, β_i is the regression coefficient and β_0 is the constant.

We also conducted focus group discussions (FGDs) to elicit how farmers perceive and what type of adaptation strategies they implement against adverse climate change impacts. Farmers were not asked to catalogue or rank these strategies but instead to discuss how their perceptions align with their responses to climate change. Twelve FGDs (2 in each village) covering 10 to 12 men and women farmers 30 to 70 yr of age were conducted across the study districts. Attempts were made to balance farmers in terms of differences in wealth status and religious background. Discussions were conducted in farmers' training centres where novel agricultural technology demonstrations were promoted by extension agents (CSA 2016). Checklists were provided to guide on how to proceed with conducting discussions and to facilitate understanding about research themes and objectives. Farmers' responses were recorded and transcribed, and afterwards analyzed through thematic content analysis (Alhojailan 2012), which allows us to pinpoint and examine patterns or themes within data and at the same time interpret different aspects of our research topic (Ayal & Filho 2017). This type of content analysis was also used in other studies that examined climate change vulnerability and adaptation assessments (Below et al. 2012, 2015, Tambo & Abdoulaye 2013, Gioli et al. 2014).

2.3. Climate data

To contrast farmers' perception with meteorological (observed) data, we obtained temperature and precipitation records from 3 weather stations, namely Tebela, Gasuba and Boditi, which are nearest to the study areas (Table 1). Observed climate data obtained cover the period 1985–2015 and do not include any months where data were missing for more than 25% of the days during the rainy season (Mekasha et al. 2013). This medium-term period was adopted to be within the range that climate change is potentially perceived at by most active farmers in the study area, although longer trends would likely allow better detection of greenhouse gas-driven warming (Niles & Mueller 2016). For months where data were missing for less than 25% of the days, mean annual precipitation and temperature were marked as missing. To keep consistency with the periods when household-level data were collected, we focus on temperature and rainfall trends for the rainy seasons (March–September). The Mann-Kendall test, which is robust to non-normal distributions and to the presence of outliers (Mulenga et al. 2016, Ayal & Filho 2017), was employed for detecting both temperature and precipitation trends. Change rates were assumed to be significant at less than 5% probability level. Annual mean and SD were calculated from monthly precipitation data. Hence, mean annual rainfall changes were calculated using the equation SRA = $(^{P_t - P_m}/_{\sigma})$, where SRA is the standard rainfall anomaly, P_t is the mean annual precipitation in year t, P_m is the mean annual rainfall over the period of observation and σ is the SD of rainfall within a specific rainy season months (Ayal & Filho 2017). Such type of analysis in combination with the coefficient of variation as the ratio of the standard deviation to the mean annual rainfall (Kassie et al. 2013) helps to determine intra-seasonal and inter-annual rainfall variability patterns.

3. RESULTS AND DISCUSSION

3.1. Household demographic socio-economic characteristics

We present an overview of household demographic and livelihood characteristics in Table 2. Nearly 54% of households have above-average landholding (0.25 ha) in the study area. Most farmers have access to information on local weather change through radio and/or television.

3.2. Farmers' perception of climate change

3.2.1. Temperature change

Most (96.7%) farmers perceived that overall temperature had increased, 1.9% of farmers recalled it had decreased and 1.5% believed it remained the same over the period 1995–2015 (Table 3). The proportion of farmers believing that temperature had increased was highest in Offa district (88.1%), followed by Sodo Zuria district (87%) and Humbo district (86%). Analyses of observed climate data exhibited a significantly ($p < 0.05$) increasing trend in terms of both mean annual maximum and minimum temperature across the weather stations (Fig. 2a–c). Hence, our findings suggested that farmers clearly perceive an increase in long-term temperature, and this is corroborated by observed climate data trends. These findings are consistent with the scientific claims about increased temperature at both local (Wilk et al. 2013, Ayal & Filho 2017, Elum et al. 2017) and global (IPCC 2007, IAASTD 2009, Oppenheimer et al. 2014) scales. This consistent temperature trend shows how climate risk is locally perceived through long-term experience in farming, and is categorized and evaluated by non-experts. In addition, the proportion of farmers who perceived an increase in temperature is much higher in our study as compared with the study of Habtemariam et al. (2016) in northern Ethiopia over the period 1990–2013. This variation may be because temperature changes have become more extreme in recent periods at levels that most farmers can perceive, particularly during the rainy seasons (Table 4). This result adds to the growing body of literature that shows increased farmers' awareness of temperature changes which have brought adverse impacts to small farm and livelihood systems (AGRA 2014, Di Falco 2014, Ayanlade et al. 2017).

3.2.2. Precipitation change

Over half (63%) of farmers perceive decreasing precipitation volumes (Table 3). The proportion of farmers who perceived precipitation decline was highest in Sodo Zuria district (66.7%), followed by Offa district (61.6%) and Humbo district (60%). The SRA shows that most years exhibited below-average

Table 2. Household demographic and socio-economic characteristics (n = 270) across the study districts. The % of respondents in each district stems from total percentage, hence adding up to 100%

Household characteristic	% of respondents Total	Humbo	Offa	Sodo Zuria
Demographic				
Household head gender				
Male	84.8	34.9	32.8	32.3
Female	15.2	31.7	36.6	31.7
Household head education level				
Primary	56.7	43.1	24.5	32.4
Secondary	37.8	30.1	36.6	33.3
Tertiary	5.6	20.0	60.0	20.0
Household head religious background				
Christian	86.7	34.2	33.8	32.1
Muslim	13.3	36.1	30.6	33.3
Socio-economic				
Household farming experience (yr)				
20–30	36.3	31.6	34.7	33.7
31–40	52.2	35.5	31.9	32.6
41–50	11.5	38.7	35.5	25.8
Households above average land holding (ha)	53.7	32.4	37.2	30.3
Households that owned television and/or radio	60.0	30.9	38.3	30.9

Table 3. Farmers' perception of climate change over the past 2 decades (1995–2015) in the study area (n = 270). Climate variable refers to the major climatic challenges that showed frequent changes over the past several decades, hence causing adverse impacts on smallholder farm and livelihood systems in sub-Saharan Africa (Kotir 2011, Simelton et al. 2011, Cairns et al. 2013, AGRA 2014, Fisher et al. 2015)

Climate variable	% of respondents Increasing	Decreasing	Remains the same
Overall temperature	96.7	1.9	1.5
Daytime temperature	81.8	12	6.2
Nighttime temperature	93.1	5.2	1.7
Precipitation volume	34.8	62.6	2.6
Rainfall intensity	75.0	19.8	5.2
Drought frequency	93.8	3.8	2.4
	More unpredictable	Late start and early end	Regular
Seasonal rainfall duration	38.9	60.0	0.7
	Climate change is both occurring and human induced	Climate change is occurring but not human induced	Climate change is not occurring and not human induced
Climate change belief	61.1	31.1	7.8

Table 4. Farmers' perception of climate trends and their belief regarding climate change during the rainy seasons over the past 2 decades (1995–2015) based on focus group discussions. For climate variable, farmers are asked to recall past climate variability trends and patterns observed over time in their farm and/or immediate neighbourhood to arrive at a conclusion beyond regions they are familiar with across the Humbo (H), Offa (O) and Sodo Zuria (S) districts. The cumulative effects of these variations over time cause a change that would result in climate change (Kotir 2011, AGRA 2014, Shiferaw et al. 2014)

Climate variable	Amount	Frequency	Duration
Temperature change	Intensity of dry and hot spell events has become much increased during the rainy seasons (H, O)	Number of both hot and dry days and nights has become much increased during the months supposed to be cool (S)	Intense hot spell occurs for several weeks or even months during the rainy seasons
Rainfall change	Rainfall amount has been much reduced during the short rainy season	It rains for a few days in late March or early April, stops for several consecutive weeks and then rains again for a few days, but at other times it rains for 7 consecutive days and then immediately stops; thus, it is unpredictable	Shortened rainy season has caused frequent dry spells (H)
Rainy season start	Shorter light rains noticed in the past are reduced for the short growing season (H, O)	Rainfall start has become later than before for the short growing season (H, O, S)	Rainfall start has shifted from early March to late April or Easter days (H, O, S)
Rainy season end	Normal rainfall is reduced, and intense rainfall has been increased, causing floods (H, S)	Rain downpours occur for a few hours and then immediately stop during the long rainy season (O, S)	Long rainy season rainfall stops in either early August or mid-July (O)
Droughts/dry spells	Drought and dry spell conditions have become more severe (H, O)	Recurrent dry spells are observed during the rainy seasons (H)	Number of days with dry spells has increased, causing maize wilting (H, O, S)
Floods	Recurrent flooding has caused land degradation (O, S)	Increased rainstorms have resulted in frequent episodes of soil erosion (H)	
Climate change	Occurrence	Direct cause	Indirect cause
	Climate change is occurring	Human action	Rapid deforestation rates due to increased demand for timber products
		Non-human action	Farmers' disobedience of 'God's Rule'

annual rainfall for all weather stations over the period 1985–2015. Observed rainfall trends were statistically significant ($p < 0.05$) and consequently were consistent with farmers' perception of reduced precipitation. These results support findings by Mulenga et al. (2016) in Zambia and by Wilk et al. (2013) in South Africa, who found consistently decreasing trends between observed and perceived rainfall, and oppose results by Sutcliffe et al. (2016) in Malawi and by Meze-Hausken (2004) in Ethiopia, who revealed a discrepancy between observed and perceived rainfall trends in the context of dryland agriculture. Such a discrepancy arises because farmers perceive decreased rainfall when they witness soil moisture decline, despite observed precipitation data showing an increasing trend.

3.2.3. Seasonal rainfall variability

Most (60%) farmers (59% in Humbo district, 54% in Sodo Zuria district and 49% in Offa district) recalled seasonal rainfall variability patterns as late start and early end (Table 3, Fig. 3). FGD participants reported that the rainy seasons have become shorter due to a shift in the start of the short rainy season

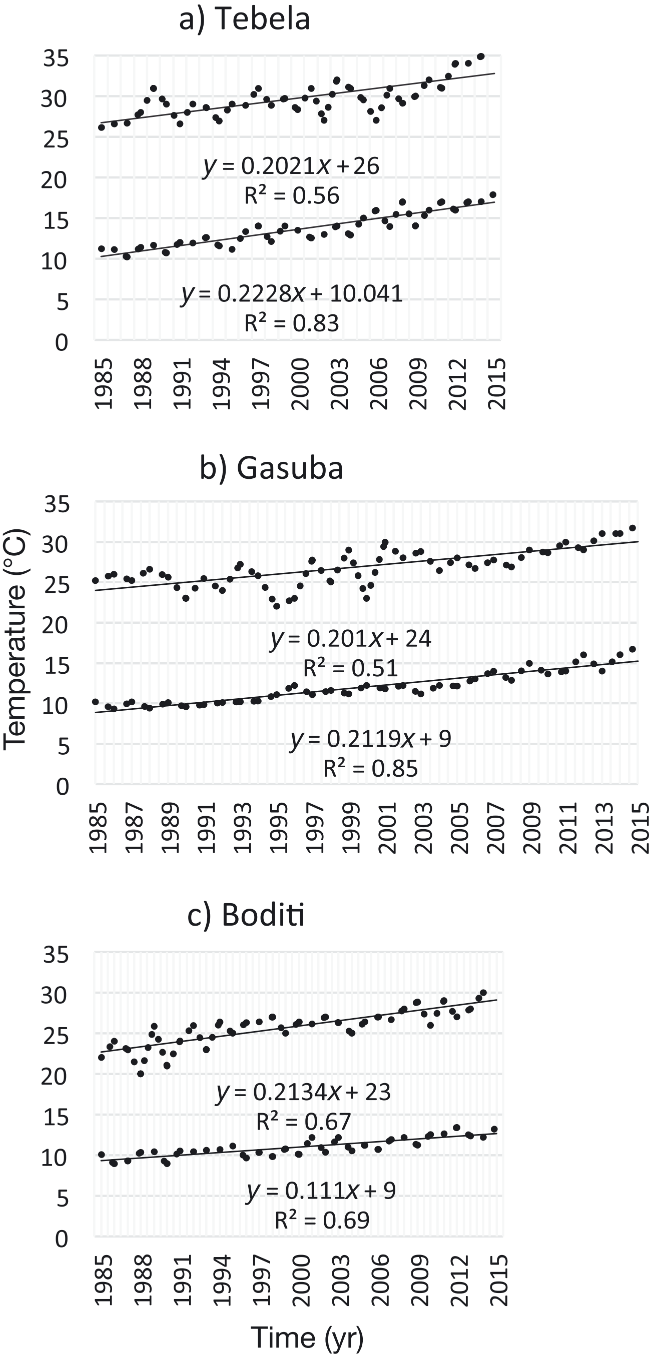

Fig. 2. Mean annual minimum and maximum temperature trends across the 3 stations (1985–2015): (a) Tebela, (b) Gasuba, (c) Boditi

from early March to late April and a shift in the end of the long rainy season from late September to early August (Table 4). They explained seasonal rainfall unpredictability by counting the number of days with rain (e.g. it rains for 3 d in early March, breaks for a week or more, rains again for 4 or 5 d in mid-April, and then breaks for several weeks). The SRA shows the general change in both short- and long-season rainfall but much more evidence of rainfall reduction in the months of the short rainy season. In addition, the number of rainy days has become lowest in March as well as September over the years 1985–2015 (Fig. 4). Such seasonal rainfall variations indicate rainy season late starts and early ends that support farmers' perception of shortened rainy season duration. This result is consistent with those of Habtemariam et al. (2016) in Ethiopia, Ayanlade et al. (2017) in Nigeria and Elum et al. (2017) in South Africa, who showed seasonal rainfall duration has become much shorter than the average rainy season duration (March–September). Simelton et al. (2011), who analyzed farmers' perception of rainfall variability patterns in Malawi, stated that households often explain intra-seasonal rainfall patterns in terms of when rain starts and ends during the rainy season. Our results do not appear to corroborate their statement; in fact, farmers primarily perceive seasonal rainfall patterns in terms of rainfall frequency within an average time frame of the rainy season (Table 3).

3.2.4. Extreme climate events

Most (75%) farmers perceive an increase in rainfall intensity, 20% reported decreased rainfall intensity and 5% believed it remained the same (Table 3). FGD participants indicated that rainfall volume had become more intense, causing erosion and flooding in lowland areas, particularly in the long rainy season, over the past 2 decades (Table 4). FGDs also revealed that dry spell and/or drought frequency has increased substantially and was responsible for maize yield decline over the period 1995–2015. Although long-term actual maize yield records were not available to analyze trends, findings show that farmers perceive change in extreme climate events such as floods and droughts. This is consistent with several findings that show both frequency and spatial coverage of dry spell and drought conditions in Ethiopia have increased significantly (Kassie et al. 2013, Adimassu et al. 2014, Abate et al. 2015). Analysis of long-term extreme climate events reported by the National Meteorology Agency (2015) over several years in Ethiopia indicates shortening of drought return periods at an exponential rate. Such extreme climate events have been occurring in Ethiopia (Conway & Schipper 2011, Shiferaw et al. 2014) and in most parts of SSA (Cairns et al. 2013, Fisher et al. 2015) over the last 2 decades, and are likely to con-

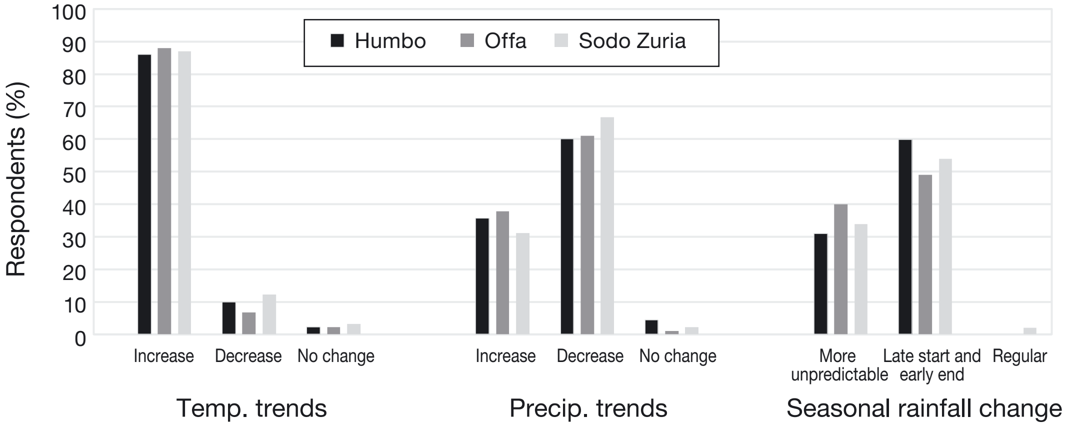

Fig. 3. Farm households' perception of past temperature, precipitation and rainfall variability trends across the 3 case study districts

tinue as long as global surface temperatures continues to rise, posing different risks to small farming communities, which often face acute food shortages (Below et al. 2012, AGRA 2014).

3.2.5. Farmers' belief regarding climate change occurrence and cause

Most (61 %) farmers who perceive climate trends (i.e. increased temperature, declined precipitation and shortened seasonal rainfall duration) believe that climate change is occurring, and is being caused by human action (Table 3). FGD participants who perceive an increase in drought frequency believe that rapid deforestation is a principal cause of climate change. They also indicated that poor access to electricity has increased household fuel wood and charcoal consumption, leading to increased forest clearing, desertification and drought, and thereby contributing to climate change. Some older participants who did not agree that climate change is linked with human actions put the blame on people that are disobedient to the Bible. Hence, climate change is believed to occur as a punishment from God. This shows that farmers' perception of climate change, to some extent, may be influenced by household age and religious background. Tambo (2016), who analyzes the effect of faith on climate change perceptions, reported similar findings in the Nigerian savanna.

3.3. Farmers' responses to climate change risks

3.3.1. Change in crop management

Nearly 57 % of farmers adjust cropping dates to better cope with fluctuations in rainy season duration and timing. The latter adjustment strategy adoption rate was 40 % in Humbo district, 29.4 % in Sodo Zuria dis-

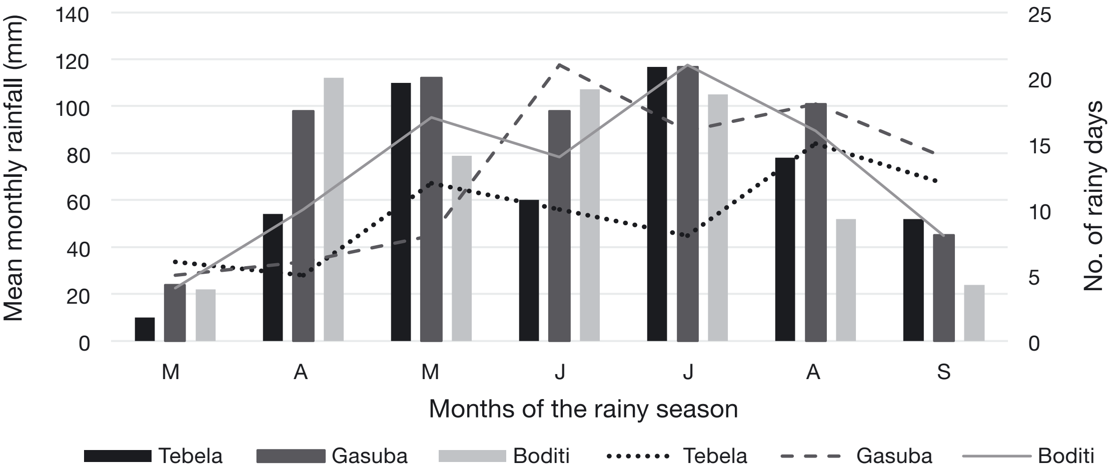

Fig. 4. Mean monthly rainfall (mm) along with number of rainy days over each month across the 3 stations (1985–2015)

trict and 30% in Offa district (Table 5). Farmers implement cropping date adjustment by shifting maize sowing date from mid-March to either late April or early May to match with the duration of the short rainy season start over the latter period. Cropping date adjustments were employed by farmers who observed low soil moisture volume and high temperature. Farmers who do not adjust cropping date sometimes sow maize seeds 2 or 3 times per plot over the same period because the increased moisture stress causes crop failure, suggesting the need for sufficient and timely weather information. Farmers in Uganda indicated that forecasts from the Uganda National Meteorological Authority, along with their own experience and knowledge, helped them decide whether or not to plant slower-maturing crops for a particular season (Hisali et al. 2011).

Table 5. Farmers' climate change adaptation strategies identified through semi-structured interviews across the study districts (n = 270). Numbers in parentheses indicate number of respondents. The % of respondents in each district stems from the total percentage, hence adding up to 100%. $^*p < 0.05$

Adaptation strategy	% of respondents				χ^2 test
	Total	Humbo district	Offa district	Sodo Zuria district	
Change in crop management					0.318*
Cropping date adjustment	56.7 (143)	40.6 (58)	29.4 (42)	30.1 (43)	
Change in crop varieties and/or type	28.2 (71)	31.0 (22)	37.9 (27)	31.1 (22)	
Crop diversification	6.7 (17)	41.2 (7)	29.4 (5)	29.4 (5)	
Either combination	8.3 (21)	28.5 (6)	42.9 (9)	28.6 (6)	
Change in farming system					0.145
Rainwater harvesting	41.3 (104)	35.6 (37)	27.9 (29)	36.5 (38)	
Agroforestry practices	47.2 (119)	37.0 (44)	37.0 (44)	26.1 (31)	
Both strategies	11.5 (29)	41.4 (12)	34.5 (10)	24.1 (7)	
Diversification beyond farm					0.108
Off-farm income activities	42.9 (108)	35.2 (38)	30.6 (33)	34.3 (37)	
Seasonal migration	49.6 (125)	36.8 (46)	36.0 (45)	27.2 (34)	
Both strategies	7.5 (19)	47.4 (9)	26.3 (5)	26.3 (5)	
Do nothing	6.7 (18)	6.5 (6)	9.64 (8)	4.5 (4)	

More than one-third of farmers across the study district employed improved crop varieties to reduce climate change risks (Table 5). About 28% of the farmers adopted open-pollinated crop varieties because of their lower costs compared to hybrid varieties. Low-cost maize varieties are prevalent because farmers have poor financial capacity to purchase improved crop varieties that provide higher yields and are drought resistant. Such improved crop varietal selection was reported to be a major strategy to adapt to climate change (Below et al. 2012). Farmers noted that yields from improved cereal crop varieties have declined sharply over the past decades, and hence they started to replace them with drought-resistant root crops such as enset *Ensete ventricosum* and cassava *Manihot esculenta* that provide more food per unit area than most cereal crops. These results are consistent with findings in north-central Ethiopia from Kassie et al. (2013) and Adimassu et al. (2014), who explored changes in crop varieties and types as major crop management adaptation strategies to climate change among small farming households.

Most farmers had shifted from a sole maize production to both maize–tuber and maize–legume mixed systems to respond to drought stress (Table 5). Crop production by combining maize with legumes, notably either common peas *Pisum sativum* or common beans *Phaseolus vulgaris*, were largely applied to build up soil fertility and prevent nutrient losses. Although changes in disease spread and severity are uncertain under climate change (Cairns et al. 2013), farmers suggest that greater crop diversity across space and time could potentially help to improve yields. At the same time, farmers acknowledge that crop diversity can protect against climate change risks because of the opportunity to plant specific crop varieties when other varieties fail. Likewise, Mertz et al. (2009) in Senegal, Tambo & Abdoulaye (2013) in Nigeria and Adimassu et al. (2014) in Ethiopia revealed that crop diversification is one of the preferred strategies by farmers to deal with adverse climate change impacts. This shows that cropping systems with greater diversity are usually more stable, as they can withstand disturbances better than less diversified cropping systems.

3.3.2. Change in farm management

The majority (47.2%) of farmers implemented agroforestry practices by combining garden plants like coffee *Coffea arabica* and avocado *Persea americana* with maize (Table 5). The belowground (soil moisture and nutrient) and aboveground (light) competitions between these trees and crops were reduced through pruning of tree roots and canopy, respectively. Others grew farm boundary trees such as *Cordia africana* and *Croton macrostachyus* in highly rugged and mountainous areas. With their deep roots, the latter types of trees can increase water retention by reducing runoff rates. In northern Ethiopia, Di Falco (2014) found that agroforestry practices are the most common climate change adaptation strategy among mixed crop–livestock producers. Malawian farmers, who grow trees like *Faidherbia albida* that provide nitrogen and crop shade during dry seasons, have obtained a better yield as compared to farmers who do not grow these trees (Sutcliffe et al. 2016). Although much experience is required to successfully combine crops and tree species on the same plot or farm (Pramova et al. 2012), agroforestry systems further provide honey and traditional medicine (Brown & Dettmann 2011), control pests and diseases (Hoang et al. 2014) and supply animal fodder (Shikuku et al. 2017).

About 41% of the farmers adopted rainwater harvesting techniques through contour ditches that retain water flowing down hills, and construction of micro-check dams that provide continuous irrigation water supply and at the same time reduce drainage congestion (Table 5). Farmers reported irrigating their farms by collecting rain and/or diverting seasonal rivers through gravity systems during the rainy seasons. Such climate change adaptation strategies not only help to alleviate water stress but could also allow for expanding opportunities for changing cropping dates and varieties as well as increasing returns on investment in fertilizers (Kassie et al. 2013, Simelton et al. 2013, Yegbemey et al. 2013). However, farmers reported 4 main challenges: (1) financial constraints to purchase water pumps; (2) increased water evaporation rates due to increased temperature; (3) poor quality of pond construction materials, leading to high water infiltration rate; and (4) high price of polythene plastic to collect and conserve rainwater during the rainy seasons. The latter challenges are also reported in South Africa by Wilk et al. (2013), in Ethiopia by Gebrehiwot & van der Veen (2013) and in Zambia by Mulenga et al. (2016). Despite these challenges, the use of rainwater harvesting practices is critical for ensuring higher production and for mitigating climate change impacts by reducing dependence on uncertain rainfall (Niles & Mueller 2016).

3.3.3. Livelihood diversification

About 43% of the farmers have off-farm income from crafting, petty trading and carpentry as a livelihood diversification strategy (Table 5). For each activity, farmers' adoption level varies depending on proximity to market centres and cities that create work opportunities. Off-farm income-generating activities improve farmers' livelihoods in times of adverse climate change impacts. By means of a household survey in north-central Ethiopia, Adimassu et al. (2014) revealed that income diversification through off-farm activities is a major climate change adaptation strategy for farmers. However, adoption of off-farm income diversification was higher in our study area than in northern Ethiopia (Kassie et al. 2013, Di Falco 2014). This variation in the adoption rate of off-farm income diversification is because the farmers in our study area are highly affected by erratic rainfall and drought, leading to low productivity and yield. Hence, most farmers employ a variety of off-farm diversification activities to make additional income and thereby to deal with adverse climate change impacts. Several studies suggest that off-farm activities provide risk insurance by enabling smallholder farmers in SSA to adopt novel coping strategies that build resilience to climate change (Di Falco et al. 2011, Erenstein et al. 2011, Simelton et al. 2011, Cairns et al. 2013).

Almost half of the farmers reported that they seasonally migrate (for 1 or 2 mo) to nearby urban areas in search of manual labour work, especially during the dry seasons. Some had also migrated to outside their communities to work on large-scale sugarcane and flower farms. Such migration allowed farmers to gain additional household income for purchasing inputs like improved crop varieties, and hence adapt to uncertain rainfall. Research in the northeastern Ethiopian highlands showed that farmers migrate to nearby towns to gain financial capital to cover costs of agricultural inputs such as fertilizer and irrigation pumps (Morrissey 2008). Although economic conditions in urban areas are becoming more precarious (CSA 2014), farmers revealed that seasonal migration helps to increase household income and thereby reduce financial constraints. Seasonal migration may nevertheless lead to a sudden increase in permanent rural–urban migration (i.e. escaping agriculture) rates in Ethiopia along the familiar networks (Di Falco 2014, CSA 2016). However, farmers reported seasonal migration as a climate change coping strategy in rural settings. This result is consistent with findings in Tanzania by both Below et al. (2012) and Yegbemey et al. (2013), who identified seasonal migration as a major coping strategy against climate change risks.

3.4. Linking farmers' climate change perception with their adaptation decisions

Results show that the likelihood function of the binary logistic model was statistically significant ($p < 0.05$, Wald's $\chi^2 = 17.46$), showing its strong explanatory power (Table 6). As expected, farmers' climate change perception appeared to have a positive and significant effect on the probability of undertaking an adaptation decision. An incremental change in farmers' perception of temperature and seasonal rainfall change increases the logs of the odds ratio by 2.366 and 2.655, respectively. These strong correlations indicate, in part, that farmers who perceive climate change can gain insights into how their livelihoods are affected by, and respond to, its adverse impacts, and thereby undertake adaptation decisions. Farmers who believed climate change is occurring as well as being caused by human action are also likely to adapt to climate change. Woods et al. (2017) suggested that farmers interpret their observations of climate change, learn from theire experience, and act according to their improved understanding of the involved risks. Findings also indicated that only highly experienced and well-educated farmers are able to explain the probability of undertaking climate change adaptation decisions. Unlike our expectation, findings show that the likelihood of undertaking a climate change adaptation decreases with farmers who have large landholdings. This negative relationship could be because farmers' decision to adapt to climate change is influenced by plot-specific characteristics rather than size. This result is in line with the study in Ethiopia by Deressa et al. (2009), who revealed a negative relationship between landholding size and farmers' climate change adaptation decision.

4. CONCLUSIONS

Our study aimed to analyze the perception of climate change by maize-dependent smallholders in Ethiopia. We hypothesized that farmers perceive both past and present climate changes. Results show that farmers perceived increased temperature, precipitation decline and shorter rainy seasons over the past 2 decades (1995–2015). Results indicate that farmers reported experiencing an increased frequency of extreme climate events such as droughts and floods. Farmers' perceived climate change trends were consistent with data obtained from weather stations (1985–2015). Farmers who perceive climate change trends believe that it is occurring and that the cause is anthropogenic, e.g. deforestation. Hence, our findings support the hypothesis that farmers perceive climate change over time.

Our study further aimed to explore the relationship between farmers' climate change perception and their adaptation decision. We hypothesized that farmers who perceive climate change adapt to it. Findings show that farmers use small but flexible response strategies such as cropping date adjustment, improved crop varieties, farm pond creation,

Table 6. Binary logistic regression model outputs. *p < 0.1, **p < 0.05, ***p < 0.01

Explanatory variable	Odds ratio	SE
Household (HH) head perception of temperature change (1 = yes, 0 = otherwise)	2.366**	2.011
HH head perception of precipitation change (1 = yes, 0 = otherwise)	0.964	0.997
HH head perception of seasonal rainfall change (1 = yes, 0 = otherwise)	2.655**	2.45**
HH head belief on whether climate change is occurring as well as being caused by human action (1 = yes, 0 = otherwise)	1.99*	1.124
HH access to information on local weather change (1 = yes, 0 = otherwise)	0.148	2.285
HH head farm experience (in number of years)	1.442***	0.188
HH access to agricultural input price information (1 = yes, 0 = otherwise)	0.154	2.378
HH access to training on novel agricultural technology (1 = yes, 0 = otherwise)	0.562	0.874
HH education level (in years of formal schooling)	2.069**	0.285
Farm size (in ha)	−0.911*	0.825
HH head gender (1 = male, 0 = female)	1.011	0.549

Model summary

Number of observations	270
Wald chi-squared	0.002
Log-likelihood ratio	17.46
Pseudo R-square	0.515

agroforestry, off-farm income diversification and seasonal migration. Results show that farmers' adaptation decisions are triggered by perception of climate change trends, as well as household access to local weather information, farm experience and farm size, suggesting that climate change adaptation is a complex and context-specific socio-cognitive and -economic process. Hence, our results support the hypothesis that farmers who perceive climate change employ different adaptation strategies.

This study enhances our understanding of smallholder farmers' climate change perception and their adaptation strategies and barriers, as well as constraints to apply them in a maize cultivation system. It has important implications for future climate change impact and vulnerability assessments, and for developing successful adaptation interventions by combining socio-cognitive factors such as perceptions. Understanding how socio-economic and cultural beliefs lead to farmers' response bias in climate change perception would help to widely integrate risk communications into adaptation plans at the local level. This knowledge would enable the development of climate change adaptation scenarios based on what farmers consider as robust, relevant and meaningful to their farming systems. Policies aimed at promoting bottom-up adaptation strategies should recognize farmers' view on and experience with climate change in order to design more effective adaptation strategies that build farmers' resilience.

Any application of this research in another context requires appropriate adjustments. It would be interesting to combine social and ecological factors that influence the degree to which farmers' perception aligns with actual response to climate change. Further research may be needed to understand the effect of household socio-economic factors such as educational level and farming experiences as well as institutional factors such as access to market and credit on the adoption of climate change adaptation strategies by focusing on specific agronomic and natural resource management practices.

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