East Africa Research Papers in Economics and Finance

East Africa Collaborative Ph.D. Program in Economics and Management

Impact of Weather Variations on Cereal Productivity and Influence of Agro-Ecological Differences in Ethiopian Crop Production

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East Africa Research Papers in Economics and Finance

EARP-EF No. 2016:07

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Preface

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Abstract

This study investigates the impact of weather variations on cereal crop productivity over a period of 15 years in Ethiopia. Consistent with previous productivity studies in sub-Saharan Africa, this study also confirms the importance and strong influence of most of the weather related variables on cereal crop productivity. Descriptive results show that cereal crop production and productivity increased over the period in the study area and in each agro-ecological zone. Average annual and seasonal rainfall distribution declined, while average annual and seasonal temperatures increased through the study period. However, the weather variables were not uniform in the agro-ecological zones. Panel data estimation results indicate which inputs significantly enhanced cereal crop productivity and which ones including weather variables (temperature and rainfall) influenced cereal crop productivity negatively. Considering the effect of the weather variables annually and seasonally, both in their linear and squared terms, the regression results reveal that productivity of cereal crops was generally sensitive to climate variables. Moreover, regression results show evidence of agro-ecological differences and crop productivity regress over time. These findings are important and can be used to initiate government policy options when planning climate change adaptation strategies and agricultural policies tailored to support various agro-ecological zones across the country. The study recommends that policies that will help improve extension services, farmers' education, supply of agricultural production inputs and developing climate change adaptation strategies suitably designed to meet the needs of different agro-ecological zones should be actively pursued.

Keywords: Weather variations, cereal crop productivity, agro-ecological zone, panel data, rural Ethiopia.

JEL Classification Codes: D24; O13; O33; O47; Q12; Q54.

1. INTRODUCTION

While climate change is a global phenomenon, its potential effects are not expected to be uniform; rather they are unevenly distributed, both between and within countries (O'Brien and Leichenko, 2008). The extent to which these impacts will be felt depends in large part on agro-climatic/ecological characteristics and the extent of local and national adaptations and adaptive capacities (Yesuf et al., 2008). There is consensus that over the coming decades, anthropogenic climate changes will cause dramatic transformations in the biophysical systems that will affect human settlements, the ecosystem, water resources and food production; all of which are closely linked to human livelihoods (IPCC, 2007). These transformations are likely to have widespread implications for individuals, communities, regions and nations. In particular, poor, natural resource-dependent rural households will bear a disproportionate burden of the adverse impacts (Adger, 2003). Research findings reveal that weather variability and climate change have significant impacts on global and regional food production systems and particularly have serious impacts on agriculture in Africa in general and in sub-Saharan Africa in particular (UN-OHRLLS, 2009).

Ethiopia is a densely populated country in Africa with over 94 million people. It is dominated by subsistent farmers making it one of the countries that are most vulnerable to weather variability and climate change in the continent. Agriculture contributes about 40 per cent of Ethiopian GDP, directly provides employment and livelihood to more than 83 per cent of the population, it contributes about 85 per cent to its total export earnings and supplies around 73 per cent of the raw material requirements of agro-based domestic industries (AfDB, 2011). However, the country's agricultural production is rain-fed and traditional, being produced predominantly by subsistent smallholders, who have less capacity to adapt to climate change; who usually cultivate land areas of less than 1 hectare; and collectively account for approximately 85 per cent of the country's agricultural production (FAO, 2009). Ethiopia's economy and ecological system are fragile and vulnerable to weather variability and climate change. The country is characterized by diverse topographic features that have led to the existence of a range of agro-climatic zones each with distinctly varied climatic conditions such as lowlands, midlands and highlands. Among these zones, the lowlands have the lowest and most erratic rainfall rates, notably the Central Rift Valley (CRV) region which also experiences frequent natural hazards such as sudden flooding, recurrent droughts and chronic water stress that are aggravated by climate change and its variability.

Ethiopia's agricultural sector, with cereals as the major food crop, is especially vulnerable to the adversities of weather variability and climate change and is characterized by poor productivity.

Cereals in Ethiopia are particularly important to the country's food security as they are a principal dietary staple for most of the population; they also comprise about two-third of the agricultural GDP and one-third of the national GDP and are a source of income for a majority of the people. Cereals are the most vital crop in the country's crop production in terms of production volume, area and agricultural farm households. According to CSA, (2014) cereals had a share of more than 79 per cent of the total crop area and 85 per cent of grain crop production for the Meher season in the 2013-14 production year, ranking the country as one of the largest cereal producers in Africa. Moreover, 81 per cent of the agricultural farmers –particularly those concentrated in the central Ethiopian midlands and highlands – practice mixed farming and are primary cereal producers.

The production of cereal crops was marked with remarkable growth in Ethiopian agricultural crop production during the last decade. Several CSA publications indicate that total cereal crop production grew consistently between 2004-05 and 2013-14, from an average of 16 million metric tons in 2004-05 to 2008-09 to 18.7 million metric tons in 2009-10 and 2013-14, averaging 17.35 million metric tons during the last decade. This shows that cereal crop production had 27.4 per cent growth between 2004-05 and 2013-14 at a rate of 2.74 per cent per annum (Table 1).

Table 1: Cereal crop production, area and yield trends for Meher season 2004-05 – 2013-15

	2004-05-2008-09	2009-10	2010-11	2011-12	2012-13	2013-14	2014-15
Hector (million Ha)	9.3	9.2	9.7	9.6	9.6	9.8	10.1
Production (million Q)	16.0	155.3	177.6	188.1	196.5	215.8	360.1
Yield (qt./ha)	14.6	16.9	18.3	19.6	20.5	22.0	23.3

Source: CSA publications; EEA (2013 and 2014).

Climate change is causing variability in weather factors such as precipitation, temperatures and soil moisture, and sometimes increased temperatures and prolonged droughts, which have compromised production of food crops in Ethiopia. In a conventional rain-fed production system, agricultural households use direct factors of production (fertilizers, seeds, labor etc.) to produce several agricultural outputs. However, farmers' abilities to operate efficiently often depend on production risks like weather factors (precipitation, temperature etc.), agro-ecological factors, operational conditions and practices such as the production environment and farm specific characteristics, for example, technology selection or managerial practices. Hence, production is influenced by weather factors, agro-ecological factors and farm characteristics which by extension affect a farmer's productive efficiency and productivity. However, despite the increasing number of climate change studies, there is dearth of literature linking climate/weather factors and the influence of environmental or agro-ecological factors on farm-level cereal crop productivity particularly in Ethiopia. In addition, the extent and impact of weather variability, impacts due to factors of production including individual household and farm characteristics on cereal crop productivity in different agro-ecological zones in the country have not been fully understood.

A brief review of literature shows that several empirical works have been undertaken to investigate impacts of climate change on Ethiopian agriculture using different methodologies. However, we found that some of these studies focus (in general) on national level assessments. Nonetheless, climate change may have area-specific effects, for example, agro-ecological based analyses may provide a better insight into the impact of weather variability and climate change on cereal crop productivity. Moreover, to the best of our knowledge, no study has analyzed the link between cereal crop productivity and agro-ecological factors under varying climatic and weather conditions. Accordingly, this research is designed to bridge this gap by providing an analysis of the impact of climate variations on cereal crop productivity. It also aims to answer the question: how do production risks --- weather factors, agro-ecological and farm and household factors -- influence cereal crop production and productivity in main cereal crop producing regions in the country?

The study makes a significant contribution to existing literature regarding the impact of weather variability and climate change on crop productivity. First, it incorporates environmental and agro-ecological factors, other exogenous factors (which are not considered in a classical Ricardian analysis) and weather factors over a shorter period of time as opposed to long-term average climate normally used in a Ricardian analysis. It bases the agro-ecological analysis considering all cropping activities on a farm and is therefore replicable elsewhere in the country and also in other developing countries. Finally, it has some advantages over existing methodologies in its approach as it introduces a methodological innovation on the impact of climate change literature by employing a combination of standard production function, production risk and damage control framework approach as a model for the study. Hence, the study provides valuable information which is needed for developing agro-ecologically-adaptive strategies in response to increasing climate variations and their impact in the country. The results can be used to infer the economic implications of climate change on targeted food crops in the country.

The rest of the paper is organized as follows. Section 2 presents an overview of climatic conditions in Ethiopia and an overview of literature on the impact of climate variations on crop productivity in developing countries, and in Ethiopia. In Section 3, the data employed and the econometric methodologies used in the study are presented. Section 4 presents and discusses empirical findings and Section 5 gives a conclusion.

2. REVIEW OF EMPIRICAL LITERATURE

Studies on the impact of climate change on agricultural crop productivity have increased over the decades, with a more recent focus on developing countries in general, and a specific focus on Africa. Most of the studies assess the extent to which adaptation options can lessen the expected impact of climate change. In the Ethiopian context, several empirical works have been undertaken to investigate the impact of climate variations on agriculture at different levels and with different research methodologies. In what follows, we review the studies that focus on the impact of climate change on agricultural crop productivity in developing countries in general followed by a review of studies on Ethiopia.

2.1 Impact of climate variations on crop productivity in developing countries

Liangzhi et al. (2005) investigated climate impact on Chinese wheat yields, using crop-specific time series and cross-section data from 1979 to 2000 for 22 major wheat producing provinces in China and corresponding climate data like temperature, rainfall and solar radiation during this period. They found that a 1 per cent increase in the temperature in the wheat growing season reduced wheat yields by about 0.3 per cent. They also report that rising temperatures over the two decades prior to their study accounted for a 2.4 per cent decline in wheat yields in China while a major growth in wheat yields, 75 per cent, came from increased use of physical inputs. Guiteras (2009) estimated the impact of climate change on Indian agriculture using the feasible generalized least squares (FGLS) estimation method. His results suggest that climate change is likely to impose significant costs on the Indian economy unless farmers can quickly recognize and adapt to increasing temperatures. The study further reported that such rapid adaptation may be less plausible in a developing country, where access to information and capital for adjustment is limited. Ayinde et al. (2010) analyzed climate change and agricultural production in Nigeria using time series data. They used descriptive statistics and a Granger causality test analysis as analytical tools. They report that temperature remains relatively constant and it does not affect agricultural output. However, they used a Granger causality approach which revealed that changes in rainfall positively affected agricultural production in Nigeria.

Lee et al., (2012) analyzed the impact of climate change on agricultural production in 13 Asian countries from 1998 to 2007. Their study used the agricultural production model and estimated a country-level fixed effect panel model for agricultural production using seasonal climate variables and other input variables. Their result showed that higher temperatures and more precipitation in summer increased agricultural production while higher fall in temperatures was harmful in South and South East Asia. On the other hand, they reported that an overall increase in annual temperature decreased agricultural production in Asian countries. The study concluded that adapting to climate change by developing new varieties that are more tolerant to higher temperatures was necessary and also recommended increasing investments in agricultural productivity and developing proper adaptation programs or policies.

Kumar and Sharma, (2013) analyzed the impact of climate change on agricultural productivity in quantity terms, value of production in monetary terms and food security in India based on secondary data for 1980 to 2009. Their regression analysis was based on the Cobb-Douglas production type model. Their results showed that climate variations had a negative impact for most of the food grain crops and non-food grain crops in quantity produced per unit of land and in terms of value of production. The reported adverse impact of climate change on the value of agricultural production and food grains indicates food security threat to small and marginal farming households. The study also reported an econometric estimation of the state-wise food security index which revealed that food security had been adversely affected due to climatic fluctuations.

Addai and Owusu (2014) analyzed the sources of technical efficiency of maize farmers across various agro-ecological zones in Ghana, based on a panel data analysis using a stochastic production frontier model for a sample of 453 maize farmers. They reported that extension, mono cropping, land ownership and access to credit positively influenced technical efficiency. High input prices, inadequate capital and irregularity of rainfall were the most pressing problems facing maize producers in the forest, transitional and savannah zones respectively. Mulwa (2015) analyzed overall farm efficiency, the influence of climatic factors and agro-ecological zone factors on farm level efficiency in Kenya using a two-stage semi-parametric model. He used rural household survey datasets for 2004, 2007 and 2010. The Tegemeo Institute of Agricultural Policy and Development, Egerton University conducted the surveys in collaboration with Michigan State University. The collected data were from 2,297, 1,342 and 1,313 households for the three years respectively spread over 24 districts in Kenya. The results indicated that farming in Kenya was highly inefficient, recording efficiency levels of 15 per cent, 12 per cent, and 18 per cent for 2004, 2007 and 2010. The study reported that temperature, rainfall, the standardized precipitation-evapotranspiration index (SPEI), altitude and adaptation strategies all influenced farming efficiency in the country negatively and positively and at different magnitudes.

2.2 Impact of climate variations on crop productivity in Ethiopia

Deressa and Hassan (2007) analyzed the economic impact of climate change on crop production in Ethiopia by using the Ricardian method. For the estimation, country-level survey data were used and the net crop revenue was regressed on climate (rainfall and temperature), household, and soil variables. They analyzed the seasonal marginal impact of climate variables (temperature and precipitation) on crop net revenue. The analysis indicates that a marginal increase in temperature during summer and winter had a negative significant effect on net crop revenue per hectare and a marginal increase in precipitation during spring had a positive significant effect on net crop revenue per hectare. Bamlaku et al. (2009) investigated efficiency variations and factors causing inefficiency across agro-ecological zones in Ethiopia using a stochastic frontier analysis. They showed that seasonal climate conditions (including rainfall and temperature) and agro-ecological settings had a significant impact on technical efficiency in Ethiopian agriculture. The study also observed that education, proximity to markets and access to credit contributed to significant reduction in farm inefficiencies. In this regard, it is necessary to understand the influence of socioeconomic characteristics, management practices and environmental factors on farm productive efficiency. Zerihun (2012) in his analysis of the impact of climate change on crop yield and yield variability in Ethiopia investigated the impact of climate change on mean and variance of crop yields over 28 years. He used a stochastic production function and estimated the effects of rainfall on crop yields and their variations and found that the effects of seasonal rainfall differed across crops and regions. His simulation results showed that negative impacts of future climate change entailed serious damage to the production of teff and wheat, but relatively maize yield will increase in 2050. In addition, they reported that the future crop yield levels will largely depend on future technological developments, which have improved yield over time despite changing climate.

Kassahun (2011) in his analysis of climate variability and its economic impact on agricultural crops using the Ricardian approach analyzed the marginal effects of temperature and rainfall on agricultural crop productivity based on farm data generated from 174 farmers. Regressing net revenue he reported that climate, socioeconomic and soil variables had a significant impact on farmers' net revenue per hectare. His results from a marginal analysis show that a 1°C increase in temperature during the main rainy and dry seasons reduced net revenues. On the other hand, a 1°C increase in temperature during the short rainy and autumn seasons was found to marginally increase net revenue per hectare. This study also reported that an increase in precipitation by 1mm during the main rainy and dry seasons reduced net revenue per hectare. Gebreegziabher et al. (2013) investigated crop-livestock inter-linkages and climate change implications for Ethiopia's agriculture in a broader sense using the Ricardian approach in the Nile Basin during the 2004-05 production year. They analyzed the impact of climate change and weather variations on agriculture, on crops and on livestock, both individually and taken together. The findings suggest that a warmer temperature was beneficial for livestock agriculture, while it was harmful for the Ethiopian economy from the crop agriculture point of view. Moreover, they concluded that increasing/decreasing rainfall associated with climate change was damaging to both the agricultural activities.

Mintewab et al. (2014) assessed the impact of weather and climate change measures on agricultural productivity of households, measured in terms of crop revenue in the Amhara region in Ethiopia. They used four waves of survey data, combined with interpolated daily temperature and monthly rainfall data from meteorological stations. Their findings showed that temperature effects were distinctly non-linear, but only when the weather measures were combined with the extreme ends of the distribution of climate measures. In addition, they reported that contrary to expectations for rain-fed agriculture rainfall generally had a lesser important role to play than temperature.

2.3 Overview of climatic conditions in Ethiopia

Ethiopia is characterized by diverse climatic conditions. The country's climatic system is largely determined by the seasonal migration of the Inter-tropical Convergence Zone (ITCZ) and a complex topography (NMA, 2001). One can identify three distinct rainfall regimes in Ethiopia classified according to annual distributional patterns. The southwest and western areas of the country are characterized by a uni-modal rainfall pattern, the central, eastern and north-eastern parts exhibit a quasi bi-modal and the south and south eastern areas a distinct bi-modal rainfall pattern (the World Bank, 2006). Mean annual rainfall ranges from about 2,000 mm over some areas in the southwest to less than 250 mm over the Afar lowlands in the northeast and Ogaden in the southeast while mean annual temperature varies from about 10^{o}C over the highlands of the northwest, central and southeast areas to about 35^{o}C on the north-eastern edges.

In addition to variations across the country, the climate is characterized by a history of climate extremes such as droughts and floods, increasing trends in temperature and a decreasing trend in precipitation (Demeke et al., 2011). Annual average minimum temperature has been increasing by about 0.25 ^{o}C every 10 years and the maximum by 0.1 ^{o}C every decade. Over time, the amount of rainfall is also exhibiting a declining trend with increasing variability. According to NMA, (2001) the country's rainfall is characterized by a high degree of spatial and temporal variability. Despite ample groundwater and surface water resources, agriculture in Ethiopia is largely rain-fed. As a result, rainfall is considered as the most important climatic element determining the performance of Ethiopian agriculture and hence its broad economy. Moreover, the rain-fed nature of agriculture underlines the importance of the timing and amount of rainfall that occurs in the country. If seasonal rainfall fails or its amount or timing deviates from the norm, agricultural production is negatively affected (the World Bank, 2006) with damaging consequences for the country's overall economy and food security. Large inter-annual weather variability, which is clearly reflected in the prevalence of recurrent droughts and floods, is a characteristic of the country's climatic system (Gissila et al., 2004). Drought events with differing scales of devastation are a notable feature of the Ethiopian climate (Demeke et al., 2011). Between 1900 and 2015 major drought events were registered in 1965, 1969, 1973, 1983, 1987, 1989, 1999, 2003, 2005 and 2008; these are before the worst ever drought in 2015.

2.4 Classification of agro-ecological zones in Ethiopia

Ethiopia is characterized by a diverse topography. The great East African Rift Valley (which runs northeast to southwest across Ethiopia), the mountains and highlands to the right and left of this Rift Valley and the lowlands surrounding these mountains and highlands in every direction can be described as the country's main topographical features. This diverse topography and various atmospheric systems in the country, in turn, result in varying climatic conditions (such as rainfall, temperature and elevation). Moreover, Ethiopia's climatic conditions range from warm and humid in the south-eastern region to semi-arid in the low-lying regions. Based on this, NMA, (1996) documented that the climate of the country can be divided into 11 climatic zones (CZs), broadly categorized as dry climate, tropical rainy climate and temperate rainy climate. These climatic conditions are directly related to ecological conditions in the country. Most importantly, the varying topography across the country and the different atmospheric circulation patterns observed, determine rainfall and temperature patterns across CZs. Average temperature, distribution of annual rainfall and the length of the crop growing period substantially vary across the different CZs in the country. Hence, based on the favorability of climatic and ecological conditions for agricultural production activities the country is broadly divided into five agro-ecological/climatic zones -- desert (hot arid), lowland (warm semi-arid), midland (cool sub-humid), highland (cool and humid) and upper highland (cold and moist) agro-ecological/climatic zones. This agro-ecological classification of the country varies greatly in terms of altitude, rainfall, length of the crop growing period and average annual temperature (Table 2). As a general rule, one can observe that the higher we move, the colder it becomes and the longer is the growing period.

Table 2: Traditional classification of agro-ecological zones in Ethiopia

Agro-Ecological Zone	Average Annual Rainfall(mm)	Altitude (meters)	Average Annual Temperature (°C)	Length of Growing Period (days)
Upper highland	1,200-2,200	>3,200	<11.5	211-365
Highland	900-1,200	2,300-3,200	11.5-17.5	121-210
Midland	800-900	1,500-2,300	17.5-20.0	91-120
Lowland	200-800	500-1,500	20.0-27.5	46-90
Desert	<200	<500	>27.5	0-45

Source: MoA (2000).

Peasant associations (FAs) selected for this study also varied in the range of their agro-climatic conditions, which enabled us to classify the study area or the study FAs into three agro-ecological zones (Table 3). Accordingly one FA (Koro-Degaga) was categorized as a lowland agro-ecological area, three FAs (Sirba-Godeti, Turufe-Kachama and Somodo) categorized as midland agro-ecological areas and FAs Faji, Kara-Fino, Milki and OdaDhawata were classified as highland agro-ecological areas.

Table 3: Classification of the study area into agro-ecological/agro-climatic zones

Region	Zone	District	FAs/survey sites	Average Annual Rainfall (mm)	Altitude (m)	Average Annual Temperature (°C)	Agro-Ecological Zone
Amhara	Dabra-Birhan	Dabra-Birhan	Faji	78.45	2,750	13.05	Highland ACZ
			Kara-Fino	78.45	2,750	13.05	
	North-Showa	Basona	Milki	78.45	2,750	13.05	
Oromiya	Arsi	Tiyo	OdaDhawata	68.89	2,211	17.20	
	East-Showa	Ada’a	Sirba-Godeti	79.77	1,763	20.6	Midland ACZ
	West-Arsi	Shasha mane	Turufe	62.33	1,937	17.82	
	Jimma	Jimma	Somodo	107.21	1,718	19.72	
	Arsi	Dodota	Koro-Degaga	72.13	1,351	21.8	Lowland ACZ

Source: Author’s calculations.

It can be observed from Table 3 that the three ACZs are fairly represented in the study sites. The midland ACZ covers the largest percentage (45.87 per cent), followed by the highland ACZ (31.55 per cent) and the lowland ACZ covering the lowest (22.57 per cent). This ACZ classification of the study area may allow inter-regional comparisons of our results. Further, according to information obtained from the agricultural bureaus in each district, there are differences in the types of major crops grown in each FA or ACZ in the study area. For instance, the dominant crop grown in the lowland areas is sorghum, whereas teff and barley are dominant in the midland and highland areas respectively. Hence, the study area is generally a traditional cereal producing area in the country.

Moreover, the central and most of the eastern half of the country that includes our study area (and hence our ACZs) have two rainy periods and one dry period. The two rainy periods are locally known as the *Meher* season (the long rainy season, which extends from June to September) and the Belg (the short rainy season, which extends from February to May). The annual rainfall distribution over this region shows two peaks corresponding to the two rainy seasons, separated by a relatively short ‘dry’ period. The dry period, which covers the rest of the year (October to January), is known as Bega. In Ethiopia crop production from the Meher season is usually harvested in September-December and this makes up the bulk of food production (90-95 per cent) and Belg production typically accounts for only 5-10 per cent of the total annual production (CSA, 2001).The failure of seasonal rains poses a risk of drought which reduces households' farm production by up to 90 per cent (the World Bank, 2003). However, the severity, occurrence and frequency of droughts varies across the country and so understanding annual and seasonal weather factors in different parts of the country or in different ACZs helps in identifying the growing seasons so that we are able to associate the weather effect and yield data to appropriate growing seasons.

3. DATA AND METHOD

3.1 Data and study area

This study employed a four-round panel data of six farmer associations (FAs) in rural Ethiopia. The data were from a panel dataset commonly called the Ethiopian Rural Household Survey (ERHS) - a longitudinal dataset collected from randomly selected farm households in rural Ethiopia in 1994, 1999, 2004, 2009 and 2014. Originally, the first four waves were conducted in collaboration by the Department of Economics at Addis Ababa University, Centre for the Study of African Economies (CSAE)-University of Oxford, UK and the International Food Policy Research Institute (IFPRI). Data collection started in 1989 on seven study sites. The 1989 survey was expanded in 1994 by incorporating other survey sites in different regions in the country. From 1994 onwards data collection has been done in a panel framework. The number of study areas has increased to 15 with the resulting sample size totaling 1,477 households. The newly included study villages were selected in order to represent the country's diverse farming systems. Before a household was chosen, a numbered list of all households (sampling frame) was developed with the help of local FA authorities. Once the list had been constructed, stratified random sampling was used to select sample households in each village, whereby in each study site the sample size was proportionate to the population, resulting in a self-weighing sample. The surveys were conducted on a sample that was stratified over the country's three major agricultural systems found in five agro-ecological zones (Dercon and Hoddinott, 2004).

The last round of the survey was extended from the original sample by forming a sub-sample of the original sample covering the six FAs following a similar sampling strategy and comprising 495 households by the researcher in 2015. This was implemented in collaboration with the Department of Economics, Addis Ababa University and the Environment for Development (EfD), at the University of Gothenburg, Sweden through the Environment and Climate Research Centre (ECRC) at the Ethiopian Development Research Institute (EDRI). The survey sites included households in six FAs in two regional states (Oromia and Amhara); regions that represented the largest proportion of the predominantly settled farmers in the country. The six FAs were selected carefully in order to represent the major cereal crop producing areas that may represent different agro-climatic (ecological) zones in the regional states in the country. The FAs were characterized by a mixed farming system, with a household having several field plots for crop cultivation and livestock grazing. The contents of the questionnaire which was extracted from ERHS focused only on those parts which were required for the intended study.

The dataset was comprehensive and addressed households' demographic and socioeconomic characteristics such as age, education and size; agricultural production inputs and outputs, livestock ownership; access to institutions; and ways of climate change adaptation and coping mechanisms of the farmers. Moreover, important secondary data needed for the study like geographical location and elevation and metrological data on climate variables mainly altitude, the latitudinal, longitudinal positions of FAs, temperature and rainfall were obtained from the Ethiopian Meteorology Authority. This included monthly observations from 1999 to 2014 collected in stations close to the study villages. The metrological dataset included monthly and annual rainfall and annual maximum and minimum temperature data that were collected by metrological agents from stations near the study villages (FAs).

Consequently, this study utilized four (1999, 2004, 2009 and 2014) rounds of data forming 446 panel households consisting of 1,648 observations that were surveyed from 1999 onwards. The four rounds were selected to allow for even time spacing and covering approximately similar time frames in data collection. The 1994 survey was excluded as it misses most of the important variables selected for the analysis.

Variables used in the analysis

The choice of study variables was guided both by a review of economic theory applications and other previous empirical work on agricultural production and productivity in general in Ethiopia and in developing countries. Agricultural production and productivity studies in developing countries including those on Ethiopia showed that direct agricultural inputs like fertilizers, land, labor, machinery use; production risk conditions (like random variations in temperature and rainfall); and households' conditions and operational practices such as demographic and farm specific characteristics for example technology selection or managerial practices affected farm production and productivity levels. However, the effect varied in time and space depending on specific situations in the study countries/areas, making it imperative to test their effects in Ethiopia's cereal crop producers.

We used monetary measures of some inputs and outputs and made their weighted aggregations at the farm or household level as this is necessary for avoiding the problem of indivisibility of input and output variables. Due to aggregation challenges different types of damage control agro-chemical variables (pesticides, herbicides, fungicides and insecticides) were converted to monetary (birr) equivalents. We compiled farm labor from three sources (traditional labor sharing groups, family labor and hired labor) of agricultural labor supply, and then converted it into man-day equivalent (MDE) units. District level prices of each crop that were collected in each round of the survey were used to convert the output produced for each crop into monetary value. Finally the monetary value of the total cereal crop production was calculated at farm or household levels.

Accordingly, total cereal crop production value per unit land for each farm called *Yield* in logarithm terms as a dependent variable was regressed on direct factors of production, weather factors, agro-ecological and farms and households' characteristics as explanatory variables. Weather variables included lagged average seasonal and annual measures computed as the mean of rainfall and temperature observations corresponding to the previous survey years and their squared terms. Seasonal weather measures included the lagged mean seasonal rainfall and temperature observations corresponding to the previous survey years for the three seasons: summer (the average for June, July and August), fall (the average for September, October and November) and spring (the average for March, April and May). The seasonal inclusion of the weather variables matched the production cycle with rainfall and temperatures fairly well within the pre-planting season, planting and growing and maturing/harvesting periods of crop production. The agro-climatic (ecological) zones' dummy variables were formed by grouping the FAs by agro-ecological zones, which are mainly climate and altitude dependent, and by a broader category that classifies FAs into high and low potential regions, which also categorizes FAs based on their potential for crop production.

3.2. Econometric methodology

3.2.1 Theoretical and empirical approaches

Agricultural production requires farmers to produce the maximum output for a given level of possible input use. However, farmers' abilities to produce efficiently often depend on production risks like variations in temperature, rainfall and other weather conditions, operational conditions and practices such as the production environment and farm-specific characteristics like technology selection or managerial practices that could in turn lead agricultural production and productivity trends to fluctuate over time. Modeling the effect of agricultural inputs on crop production is not straightforward as the standard production function (for example, CDPF) suggests. The manner in which certain inputs such as damage control ones (insecticides and herbicides), contextual variables (that characterize operational conditions and practices) and production risk-weather factors enter the production function has led people to question the conventional Cobb-Douglas specification. In previous studies, inputs are presumed to directly increase potential yields as in CDPF. However, other studies reveal that some inputs (in damage control inputs) do not directly increase potential yield but rather reduce damage to potential yields. Thus, productivity assessment from such production factors/inputs is not as straightforward as that from direct (yield increasing) inputs.

Lichtenberg and Zilberman (1986) were the first to propose a control model to discuss the special nature of damage control inputs for insecticides that distinguishes insecticides as damage-abating rather than as a yield-increasing input and to account for this characteristic using a built-in damage control function. Subsequently, there has been some debate about the appropriate way to model productivity assessment in agriculture under different operational and risk conditions and practices (see, for example, Carpentier and Weaver, 1997; Kuosmanen et al., 2006). Consequently many studies adapted Lichtenberg and Zilberman's (1986) study by using a different functional form for the production function as well as unique estimation procedures, noting the importance of such factors including weather variables in both the production function and damage abatement function in impact and productivity assessment.

For this study we followed Lichtenberg and Zilberman's (1986) approach to accommodate production risk-weather factors, operational conditions and practices in agricultural crop production and productivity assessment. They have argued that inputs such as pesticides, which control pests cannot be treated like fertilizers, because fertilizers are directly used in crop production, while pesticides are used to control any pests that may attack the plants and hence are damage control inputs. The same argument can be used for weather variations or climate change adaptation strategies, agro-ecological and households' characteristics. For example, a strategy such as increased irrigation or considering weather factors such as changing temperatures or even agro-ecological characteristics like altitude and household' characteristics like the age of the household head or his educational level cannot enter the production function directly, though they have a bearing on the level of production. In the climate change setting, this calls for specifying climatic factors and the agro climatic-climate variation function alongside the usual production function.

Lichtenberg and Zilberman (1986) modeled the damage control function with a separable structure as:

(1) $$y = F\left(x^D, g(x^P, Z)\right)$$

where x^D is vector of direct inputs (labor, seed, fertilizers and land), x^P is vector of damage control inputs (such as pesticides) and Z is vector of damage factors. Assuming the same argument in a climate change setting and using the formulation of Lichtenberg and Zilberman (1986) and Kuosmanen et al., (2005), we assume that weather factors, agro-ecological zone and households characteristics influence yield but not in the same manner as direct inputs. Hence, we assume that crop production yield is subject to weather factors, agro-ecological factors and household and farm characteristics and can be modeled as a composed function of a conventional production function and a function of non-conventional factors of production with a separable structure.

For this we assumed n = (1, … , N) farm households operating in time periods denoted by t = (1, …, T) using a technology sub-set Γ denoted by $X^D = \left(x_1^D, ..., x_n^D\right) \in \Re^{N+}$ vector of direct inputs (labor, seed, fertilizers and land), used to produce a non-negative vector of farm outputs denoted by $y = (y_1, ..., y_m) \in \Re^{M+}$. In a changing climate with variable weather patterns, agricultural households with household and farm characteristics $\upsilon = (v_1, ..., v_m) \in \Re^{G+}$ and farm characteristics (such as number of plots under cereal cultivation, participation in agricultural extension and credit services and use of irrigation), denoted by the vector $Z^I = \left(z_1^I, ..., z_r^I\right) \in \Re^{R+}$; the production risk facing farmers due to extreme conditions of variability in weather factors (precipitation and temperature) denoted by the vector $W = (w_1, ..., w_s) \in \Re^{S+}$. These farmers also operate in certain agro-ecological zones which have a range of climatic conditions (rainfall, temperature and elevation) with characteristics denoted by the vector $E = (e_1, ..., e_m) \in \Re^{D+}$. Hence assuming that cereal crop productivity is subject to weather factors, agro-ecological and household characteristics can be modeled as:

(2) $y = F\left(X^{D}, g(Z^{I}, W, E)\right)$

Assuming multiplicative separability of the weather factors, agro-ecological and households' characteristics from production activities (Kuosmanen et al., 2005), the function F can be equivalently expressed as:

(3) $y = f(X^{D})\, g(Z^{I}, W, E)$

where f is a function of vector ***X*** and consists of conventional, directly yield-enhancing inputs such as labor and seeds and g is a function of vectors of non-conventional factors of production such as Z as a vector of indirect inputs such as farms and households' characteristics, W as a vector of production-risk related weather factors and E as a vector consists of agro-ecological characteristics. In this formulation we used the conventional Cobb-Douglas functional form for the *f*(**.**) function for yield-enhancing inputs. On the other hand, previous literature does not offer definitive guidance as to the proper functional form of the *g*(**.**) function, though several cumulative distribution functions, such as logistic, Weibull and exponential functions are available. However, the exponential functional form has been used in most empirical works, and it generally represents weather factors well and tends to be more flexible (Qaim and Zilberman, 2003; Shankar and Thirtle, 2005). Thus we used the exponential functional form for the *g*(**.**) function in this study.

Further, as Carpentier and Weaver, (1997) have pointed out for the requirements of multiplicative separability we assumed that: (a) function f(.) so as to exhibit constant returns to scale (that is, linearly homogeneous in direct inputs); and (b) the influence of function g(.) are independent of the mixture of direct inputs f(.). But Kuosmanen et al., (2005) were able to demonstrate that this condition does not imply that f(.) and g(.) have no interdependencies or have no substitution possibilities or their marginal products will be independent using total differentiation. Extending this to climate change, multiplicative separability does not imply that direct inputs, weather factors and agro-ecological characteristics have no interdependencies or that their marginal products will be independent. Hence, based on these theoretical and conceptual approaches by defining:

(4) $f(.) = \beta_0 \prod X_{nt}{}^{\beta}$ and $g(.) = \exp\left(\sum W_{nt}{}^{\delta} + \sum Z_{nt}^{\eta} + \sum E_{k}^{\alpha}\right)$;

We formulated a more effective functional form of a crop yield model using a panel data context based on single-equation production model as:

(5) $Y_{it} = \beta_0 \prod X_{nt}{}^{\beta} \exp \sum W_{nt}{}^{\delta} + \sum Z_{nt}^{\eta} + \sum E_{k}^{\alpha} * e^{\varepsilon_{nt}}$

where β, δ, α and η represent the regression coefficient for respective variables to be estimated and ε_{nt} is the composite error term. All other variables maintain their previous definitions.

3.2.2 Empirical model specification

For empirical applications after including the major variables (weather/climatic factors and production factors), incorporating possible non-climatic factors such as household demographic and socioeconomic characteristics (HHC), agro-ecological factors and time dummy variables in Eqn 5, we specify the household specific cereal crop yield empirical model using a panel dataset as:

$$(6) \qquad Y_{it} = \beta_0 \prod X_{nt}{}^{\beta} \ \exp \ \sum CliV_{nt}{}^{\delta} + \sum HHC_{nt}^{\eta} + \sum AgEV_k^{\alpha} + Year_t^{\mu} \quad * e^{\varepsilon_{nt}}$$

Eq 6 can be transformed into a logarithmic form to obtain the following log-linear equation:

(7)

$$\ln Y_{nt} = \beta_0 + \sum_{j=1}^{7} \beta_j \ln X_{nt} + \sum_{h=1}^{16} \delta_h CliV_{n(t\ 1)} + \sum_{i=1}^{6} \eta_i HHC_{nt} + \sum_{k=1}^{2} \alpha_k AgEV + \mu Year + \varepsilon_{nt}$$

where ln is the natural logarithm; Y is total cereal production in monetary value per unit land or yield of the n-th household at time t; X is the jth direct agricultural input quantity including fertilizer, agro-chemicals and machinery use of the nth household at time t. *HHC* is demographic and socioeconomic characteristics of the nth household/farm at time t, and includes household's sex, age, family size, educational level, plots under cereal cultivation, participation in agricultural extension and the likes. *CliV* are climate variables of the nth household/farm at time (t-1); these include both the linear and quadratic terms of annual and seasonal weather variables corresponding to the previous survey years. *AgEV* are a set of regional dummy variables - the agro-ecological characteristics are included to represent time-persistent factors -- and account for productivity differences that could result from variations in weather and overall agro-climatic conditions that vary between periods that could not be captured by other factors included in the model; finally *year* as years in the panel period has been used as a proxy for technical change in crop production due to technological change over time. β, δ, α, η and μ are the regression coefficients for respective variables to be estimated and $\varepsilon_{nt} = c_n + u_{nt}$ is the composite error term in the model which is decomposed into an unobserved heterogeneity (c_n) and idiosyncratic error (u_{nt}) components.

The introduction of quadratic terms reflects the non-linear relationship between cereal crop productivity and weather variables. One expects that cereal crop productivity will have a U-shaped or hill-shaped relationship with weather variables. When the quadratic term is positive, the monetary value (cereal crop productivity) function is U-shaped and when the quadratic term is negative the function is hill-shaped. The idea is that for each crop, there is a known temperature and rainfall range in which that crop grows best across the seasons, although the optimal temperature and rainfall varies from crop to crop (Mendelsohn et al., 1994).

In our model, crop productivity and direct production input variables have been included in their logarithmic forms in order to provide convenient economic interpretations and to reduce heterogeneity of the variance of production. Climatic factors and household and farm characteristics entered the equation in a linear fashion. Hence, we made the interpretation for the explanatory variables using elasticities as we used a combination of log-log and log-linear functional form in the model specification. The coefficients reflect percentage change in crop productivity in response to percentage changes in respective production inputs. However, the calculation of elasticities depends (Nisrane et al., 2011) on the way in which explanatory variables are specified. For those that are specified in logarithmic form, their coefficients themselves are the elasticities and as such were directly interpretable. For those that enter the equation in a linear fashion, the coefficient estimates of these variables do not represent elasticity; instead they represent the change in the logarithm of the monetary value of cereal crop output per cereal cultivated area for a unit change in the respective inputs. That is, for these variables, $\beta_j = \partial \ln Y_{it} / \partial X_j$, and the elasticity of value of output with respect to these inputs is calculated as $E_{YX} = (\partial \ln Y_{it} / \partial X_{it}) * X_{it}$ where Y_{it} is the monetary value of cereal crop output per cultivated area, and X_{it} is mean value of input X, where X is an input entering the equation linearly. For dummy variables such as participation in the governmental extension package and agro-climatic zone dummies, $\beta_j = \partial \ln Y_{it} / \partial X_j$ is not defined because it is discontinuous. However, Halvorson and Palm Quist, (1980) as cited by Nisrane et al. (2011) show that the elasticity of value of output with respect to those dummy variables is given by $E_{YX_{DV}} = Exp(\beta_{DV}) - 1$, where X_{DV} represents the dummy variable and β_{DV} is its estimated coefficient.

4. EMPIRICAL RESULTs AND DISCUSSION

4.1. Descriptive results

Table 4 presents the descriptive summary and evolution of cereal crop production output and input variables and major households' characteristics. The farmers were able to produce on average 19.5 quintals of cereals during 1999 to 2014, with a minimum of 0.3 and maximum of 511 quintals. Observing this year by year, the mean of cereal crop production output and yield (productivity) both in quantity and monetary value terms increased over time in the sample during the study period. Mean of cereal crop production output was about 12.6 quintals in 1999 which rose steadily to 30.2 quintals in 2014. In terms of yield captured in quintals per acreage, farms had a mean of 9.6 units in 1999 which rose to 21.2 units in 2014. Average yield in terms of monetary value at constant prices was 17,000 for the four waves and grew consistently from the lowest value of 2,300 birr in 1999 to the largest value of 26,500 birr in 2014; this was an average annual growth rate of about 5 per cent. For such production farmers used an average of 342.7 man-day units of labor and on average 188 kilograms of seeds were sown or cultivated on an average of 2.6 hectares of farm land. This shows that average farm landholdings in the sample were below 3 hectares. Fertilizer application was minimal with an average of 116.1 kilogram per household; while the expenses on average were 133.9 birr for agro-chemicals (pesticides, herbicides, fungicides and insecticides) per household.

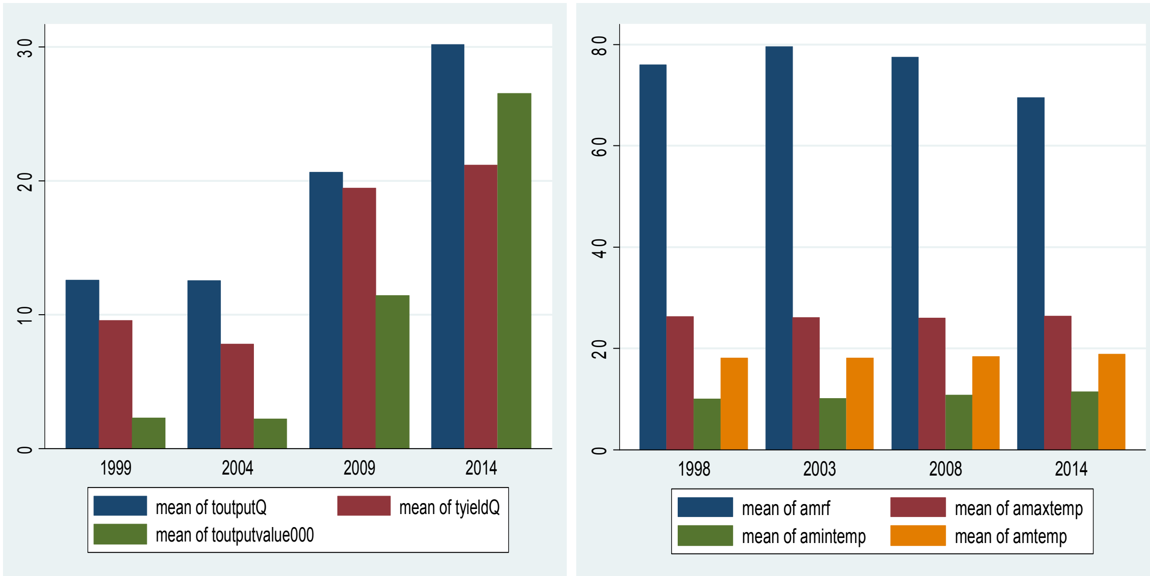
Table 4: Descriptive statistics of input-output variables and some household characteristics

Years	1999		2004		2009		2015		All waves	
Variable	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Total production(Q)	12.6	13.2	12.5	13	20.7	23.9	30.2	40	19.5	27
Yield (Q/ha)	9.6	7.3	7.8	9	19.5	55.6	21.2	29.8	15.1	34
Prod.value ('000' ETB)	2.3	4.9	2.2	2.7	11.4	17.1	26.5	35.7	11.3	23
Yield value('000' ETB)	5.1	5.6	5.5	7.1	32.7	75.2	21	26.1	17	43
Fertilizer (kg)	107.8	115.1	88	140.9	81	104.3	179	166.2	116.1	139
Agrochemicals(ETB)	26.9	71.5	23.7	77	114.7	461.5	336.7	675.5	133.9	447
Farm labor (MEU)	316.3	423.9	266.2	290.7	170.8	241.4	593.9	1222.2	342.6	714
Machinery(ETB)	0.6	4.6	41.3	301.4	836.8	3216.4	376.4	915.5	336.3	1776
Livestock(TLUs)	5.7	4.3	4.5	4	7.2	6.3	7.9	7.4	6.5	5.9
Farm size(HEC)	1.5	1.1	4.9	22.6	2.8	14.2	1.8	1.4	2.6	12.4
No of oxen	1.8	1.2	1.4	1.3	1.9	1.5	1.9	1.4	1.8	1.4
No of plot	3.4	2.3	3	1.8	4.2	2.9	3.7	2.4	3.6	2.4
Household's head age	51.1	15.5	52.8	15.8	51.5	15.5	49.7	14.7	51.2	15.4
Household's family size	6.2	2.9	4.6	2.3	5.6	2.7	6.1	2.8	5.7	2.7
Head educ. (years)	4.3	6	4.5	6.4	6.3	7.1	4.6	5.5	5	6.3
N	446		310		446		446		1648	
Sample per cent	27.06		18.81		27.06		27.06		100.00	

Source: Author's calculations.

The number of plots cultivated by farmers for cereal crops, which is also used as a proxy to measure land fragmentation among subsistent smallholders averaged 3.6 with a maximum of 16 plots. The average livestock ownership was 6.5 units (tropical livestock units) and average oxen ownership was around 1.8 that is almost two oxen per farm household. For combined panels, a majority of the farmers were male, in which male-headed households constituted 1,262 (76.58 per cent) of the total sample. The age of the household head is an important factor as it determines whether the household benefits from the experience of older farmers or the risk taking attitude of younger farmers. For this panel, mean household age was about 51.2 years, while household size ranged from 1 to 18 members, with a mean of approximately 6 members. Household size has an important implication for agricultural labor supply and household food security issues. A large family size could imply availability of adequate labor and more demand for household consumption. A total of 631(38.29 per cent) of the farmers reported contact with extension agents but very little contact with extension agents in a month (1.6 times on average). Combining the four panels, the educational levels of household heads also varied over the years with mean schooling being 5 years.

Figure 1: Average cereals production, yield and weather variables by years (1998-99 to 2014)

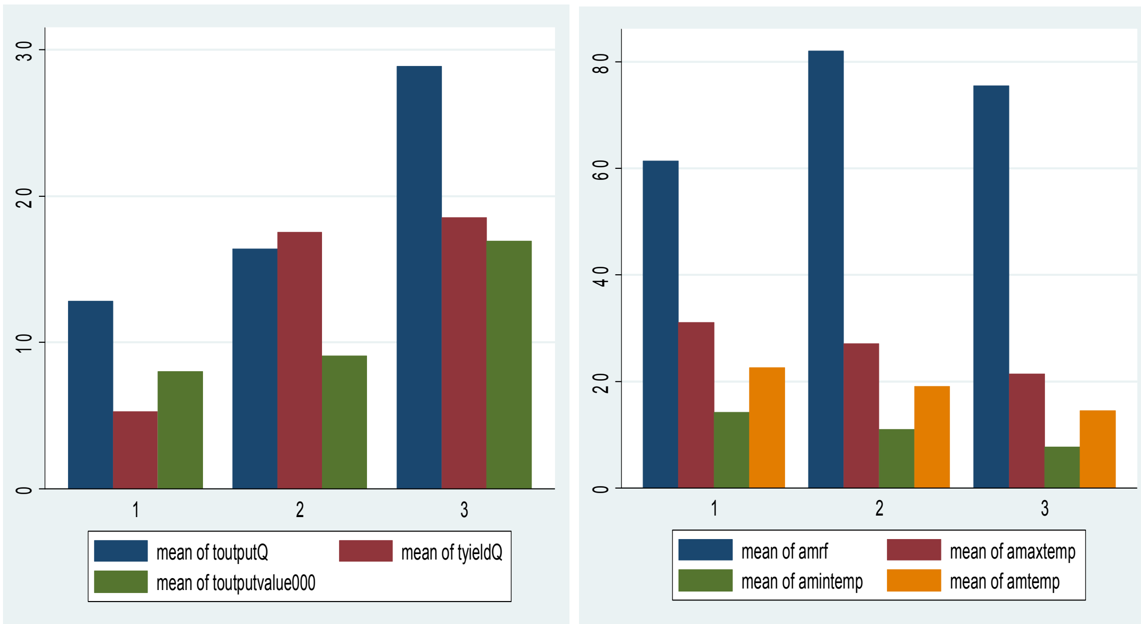


Looking at climate variables in the study area we find that a range in altitude from 1,351-2,750 meters with mean of 1,953 meters above sea level. For the four panels, the mean average annual rainfall was 75.35mm while mean of average annual maximum temperature was 26.20^{o}C and average annual minimum temperature was 10.66^{o}C. When we see the trend of weather variables annually, we notice that average annual rainfall distribution declined over time as the mean of average annual rainfall in 1998 was 79.60 mm which showed a slight decline in 2014 to 69.57 mm (Figure 1). Whereas the distribution of annual average temperature increased over time -- mean average annual temperature in 1998 was 18.11^{o}C which showed a slight increase to almost 19^{o}C in 2014, averaging 18.4^{o}C for the study period. In general, for the four panels the descriptive summary shows that there was significant variability in weather factors during the study period. It shows a decline in annual rainfall by almost 10 mm on average and an increase in annual temperature by 0.89^{o}C on average for the study period indicating that annual rainfall declined by 0.67 mm per year while annual temperature increased by 0.059^{o}C per year for the study period.

A comparison of the agro-ecological zones

When we look at crop production outputs and yields across ACZs, we find that as one moves from lowland zones to highland zones, crop yields increase. Figure 2 shows that the mean of output and productivity was higher in highland areas followed by midland ACZs; while the least output and yield is observed in lowland areas.

Figure 2: Average cereal production, yield and weather variables by ACZs



In general, looking at climate variables across agro-ecological zones the mean average annual rainfall, maximum and minimum temperature in the lowland areas was 72.1 mm, 30.6°C and 13.0°C respectively. Similarly mean average annual rainfall, maximum and minimum temperature in midland ACZs was 72.1 mm, 26.5°C and11.4°C respectively, while that in highland ACZs was 78.7 mm, 20.0°C and 6.1°C respectively.

On the other hand when we see crop production, yield and climate variables over the panel years in each ACZ we find that the mean crop production output and yield rose steadily over the period in each ACZ. This shows that crop production output and yield increased over time in all ACZs. However, as can be seen in Figure 3, average annual climatic variables over the panel round years in each ACZ were not uniform for all climatic variables, for example, it seems that rainfall declined in both midland and highland ACZs while their temperatures tended to rise. In the case of lowland ACZs the trend seems to be the opposite of that in other ACZs.

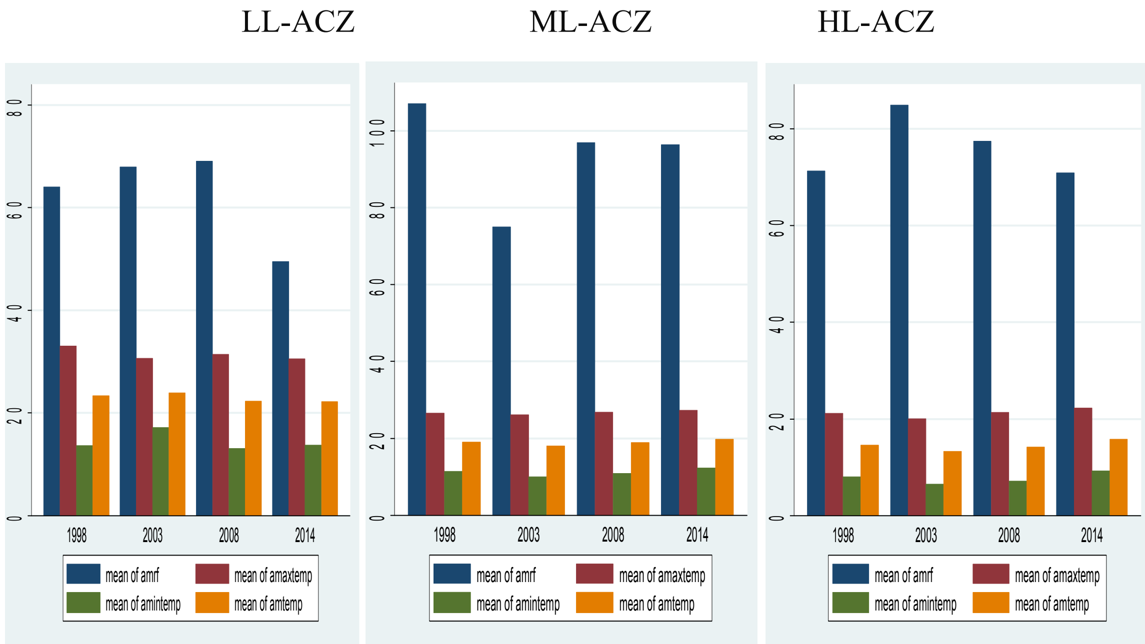


Figure 3: Average weather variables over panel years in each ACZ

4.2. Econometric regression results

For the econometric analysis several multiple regression models were run to select an appropriate panel model. Certain variables in different models were dropped from the regression due to their high insignificant levels. Finally, the random-effect and fixed-effect regression models were used. The random-effect regression model was used to identify the impact of agro-climatic or regional differences on the dependent variable and the fixed-effect model was used to identify the time effect in the data (Gupta et al., 2012). Besides, several estimation diagnoses for the econometric models were also performed.

In order to check for collinearity among the explanatory variables, correlation coefficients among all the variables were checked. Correlation coefficients verified that cereal crop productivity, as expected, was unconditionally positively correlated with direct production inputs like fertilizers, agro-chemicals, livestock ownership, machinery and number of oxen, while it was negatively correlated with labor and cultivated farm land size. Only pairs of weather variables showed a correlation higher than 0.50 indicating serious multi-collinearity and possible confounded effects. The remaining pairs had a low correlation with each other and did not show any signs of serious multi-collinearity. Age of the household head and temperature variables were negatively correlated with cereal crop productivity, while the remaining variables were positively correlated with cereal crop productivity.

Another potential problem may be omitted variable bias where some temperature-related variables that affect the yields of cereal crops may have been left out. For this we performed the Ramsey, (1969) regression specification error test (RESET) for omitted variables. The test under the 'Ho: model has no omitted variables', reveals that (Prob>F=0.1136>0.05) which indicates that there were no omitted variables for this particular model; therefore, there was no need to improve the specification of the model. To check for the presence of unobserved household heterogeneity the Breusch-Pagan Lagrange Multiplier test for random effects was used. The results of the test revealed that there was no unobserved household heterogeneity, as $H_{0:}$ (no unobserved household heterogeneity) was not rejected as the p-value was greater than 0.05.

To check fixed and random effect regression model estimates, the Hausman specification test (Wooldridge, 2002) was used. It tests a null hypothesis that random effects estimation gives consistent and efficient coefficients versus an alternative hypothesis that random effects coefficients will be inconsistent. The result of the test rejects the null hypothesis that random effects estimation is appropriate as its p-value is less than the 1 per cent critical level. This shows that fixed-effects is a more efficient model as compared to the random-effects model. Accordingly, the interpretation reported is primarily based on the results from fixed-effect estimation for time varying variables. Furthermore, for the heteroscedasticity test we used a heteroscedasticity robust method; robust standard errors are often reported when applied to cross-sectional or longitudinal studies, especially when there is a heteroscedasticity problem (Wooldridge, 2002). Since our model passed all the regression hurdles we conclude that the model adequately fit the data.

An analysis of estimation results

Table 5 presents the regression results on the panel dataset. In general it can be seen from the table that almost all parameter estimates from the model given by Eq 7 have the expected signs and all are significantly different from zero at the 5 per cent level or below obtained from either of the two models. Thus, the models adequately fit the dataset. Moreover, the use of robust standard errors helps the model to diminish heteroscedasticity. In particular, the random-effects estimates for parameters of most of the explanatory variables are significant at the 5 per cent level or below with the expected signs. The fixed-effect estimates differ slightly from random-effect estimates with some improvements and all parameters are still significant at the 5 per cent level or below for both models. Hence, after assessing the models' estimates we choose to refer to the fixed-effects results, except for the agro-climatic dummy variables that were used to identify the impact of agro-climatic or regional differences on the dependent variable.

As expected, most of the direct production inputs and household characteristics' variables impacted cereal crop productivity in the right way and were significant in the model. As shown in Table 5 the coefficient for agro-chemicals and livestock ownership was measured in TLUs and the number of plots on which cereal crops were cultivated; participation of farmers in government agricultural extension services significantly enhanced cereal crop productivity levels. On the other hand, the coefficient for cereals sown/cultivated, farm land size (area in hectares), household head's age and his education negatively and significantly impacted cereal crop productivity levels. The estimated coefficients of agro-chemicals' (pesticides, herbicides, fungicides and insecticides) use were statistically significant, depicted positively significant enhancement on cereal productivity levels at the 1 per cent significance level. Its elasticity implies that increase in agro-chemicals use by 1 unit increased cereal productivity levels by 0.037 per cent. This implies that farmers who used agro-chemicals during cultivation were more productive compared to farmers who did not spray their farms.

Consistent with our expectations, the variable used as proxy for wealth and livestock asset endowments measured in TLUs was positively and significantly associated with cereal crop productivity at the 1 per cent significance level, implying that the more livestock a household had the better its cereal crop productivity levels. Its elasticity indicates that an increase in livestock numbers by 1 per cent increased output by more than 0.125 per cent. The positive sign for livestock ownership indicates that the availability of this asset was essential in several respects. For instance, farmers with more livestock units, which can readily be converted to money, can buy modern farm inputs such as seeds, fertilizers and other chemicals, than those who own fewer livestock units. Moreover, apart from smoothing their incomes, families with more animals are more likely to have larger protein intakes than those with fewer animals, which helps improve their working efficiency. They also use dung cakes to fertilize homesteads. Besides, pack animals are used for timely transportation of the crops to a threshing point. Since threshing is conducted using animal power, the availability of livestock, especially during peak periods is vital. It helps reduce post-harvest loses. The results in this study are in line with the findings of several other empirical works (Ahmed et al., 2002; Nisrane et al., 2011).

The number of plots that farmers cultivate was included in the analysis to assess the effect of dissected plots for a given size of cultivated land on farming productivity; this was positively and significantly associated with cereal crop productivity at the 1 per cent significance level. The positive coefficient on this parameter implies that for a given number of plots, cultivating larger plots increased productivity. The results imply that for a given amount of land for crop cultivation, an increase in the number of plots for cultivation leads to increased cereal crop productivity levels. The sign on this coefficient may also represent the reduced risk that different plots provide if the plots are sufficiently disbursed, such that farmers face different degrees of weather-induced variations and mineral content. Moreover, the result can be explained in terms of access to farm land and that farmers with more plots are likely to adopt innovations because they may be willing and able to bear more risks than their counterparts and may have preferential access to farm inputs and this will enable them to improve the level of their crop production and productivity. Its elasticity indicates that an increase in the number of plots that farmers cultivate by 1 per cent will increase cereal crop output and hence increase productivity by more than 0.023 per cent.

Table 5: Regression results: Impact of climatic and non-climatic variables on cereal crop productivity (*N: households* = 446, *observations* = 1,648)

Explanatory Variables	Dependent Variable: Ln Aggregate yield of Cereal Crops	
	Random effect Model	Fixed effect Model

	Coeff.	StdErr (Robust)	Coeff.	StdErr (Robust)	Elasticities
Ln fertilizer	0.044***	0.015	0.020	0.017	0.020
Ln agrochemicals	0.039***	0.012	0.037***	0.013	0.037
Ln farm labor	0.042**	0.023	0.024	0.025	0.024
Ln machinery	0.025*	0.015	0.019	0.017	0.019
Ln livestock	0.191***	0.029	0.125***	0.037	0.125
Ln cultivated land size	-0.284***	0.059	-0.303***	0.062	-0.303
Ln of oxen	0.157***	0.053	0.091	0.063	0.091
Number of plots cultivated	0.069***	0.010	0.054***	0.012	0.023
Household's head age	-0.020**	0.010	-0.025**	0.011	-0.149
Household's head age^2	0.016*	0.009	0.019*	0.010	0.130
Household's family size	0.008	0.009	0.015	0.011	0.010
Household's head educ.	-0.002	0.004	-0.007*	0.004	-0.004
Agricultural Ext. service	0.113**	0.047	0.099*	0.057	0.104
Annual precipitation	0.043	0.039	0.281***	0.054	2.501
Annual precipitation^2	-0.015	0.013	-0.076***	0.017	-1.082
Summer precipitation	-0.031***	0.008	-0.017	0.013	-0.323
Summerprecipitation^2	0.008***	0.002	-0.002	0.003	-0.153
Fall season rainfall	-0.106***	0.021	-0.016	0.028	-0.125
Fall season rainfall^2	0.06***	0.012	0.009	0.016	0.123
Spring precipitation	0.017*	0.009	-0.052***	0.012	-0.313
Spring precipitation^2	-0.009*	0.004	-0.003	0.007	-0.025
Annual temperature	-2.468	1.832	-12.700***	2.830	-27.764
Annual temperature^2	2.574	4.790	28.950***	6.907	24.057
Summer temperature	1.011	0.912	-4.800***	1.091	-11.045
Summer temperature^2	-1.412	2.209	11.800***	2.606	10.825
Fall temperature	-5.218***	1.482	9.700***	2.273	20.142
Fall temperature^2	13.300***	3.437	-22.2***	5.358	-17.21
Spring temperature	8.343***	1.814	7.673***	2.370	17.772
Spring temperature^2	-15.400***	3.944	-18.100***	5.066	-16.839
Highland ACZ	5.136***	0.857	-	-	169.107
Midland ACZ	2.665***	0.487	-	-	13.364
Year	0.129***	0.010	0.078***	0.011	0.009
Constant	-281.800***	24.532	-152.800***	23.337	

F-statistic	Wald chi^2(32) = 3151.26***	F(30, 445) = 77.01***
R-squared	Within = 0.5931	Within = 0.6121
	between = 0.6026	between = 0.0096
	overall = 0.5968	overall = 0.1174

Note: * p< 0.05; ** p< 0.01; *** p< 0.001.

The regression results further indicate that the land size/area on which cereals are cultivated had a negative and significant impact on cereal crop productivity, which conforms to the inverse farm size-productivity relationship found in other studies. The result is significant at the 1 per cent significance level. Hence, estimated elasticity shows that an increase in cereal land under cultivation by 1 per cent will decrease cereal productivity by 0.303 per cent. Similar directions were obtained by Tesfay et al. (2005) in Ethiopia and by Basnayake and Gunaratne (2002) in Tanzania.

Estimates of the educational level of the household head show that education affects cereal crop productivity positively and significantly at the 5 per cent significance level. The positive sign for education indicates that increase in human capital enhances the productivity of farmers since they will be better able to allocate family-supplied and purchased inputs, select the appropriate quantities of purchased inputs and choose among available techniques. Its elasticity indicates that an increase in a household's educational level by 1 per cent will increase cereal crop productivity by 0.004 per cent. The results are in line with Battese and Coelli's results (1995), who hypothesized education to increase a household's ability to use existing technologies and efficient management of production systems and hence attaining higher productivity levels.

Among the socioeconomic variables, access to formal extension services as public support to farmers represented by the participation of farmers in governmental agricultural extension services and the number of extension visits received by a farmer turned out to be significant and had a positive impact at the 10 per cent significance level. The results reveal that increased access to extension services and more contacts with extension agents were associated with improved farming information, which is important for crop productivity. Thus ceteris paribus, the corresponding regression elasticity shows that an additional increase in participation and number of contacts with extension agents could lead to a rise in cereal crop productivity by 0.104 per cent.

Age of the household head had a negative and significant impact on cereal crop productivity at the 5 per cent significance level, while its square affected positively and significantly at the 10 per cent level, indicating age has a non-linear relationship with crop productivity. This further indicates that older household heads are less productive as compared to younger ones. Moreover, the result can be explained in terms of crop production practices. The negative sign for the coefficient could be attributed to the unwillingness of older and more experienced farmers to have contact with extension workers and that they were equally less inclined to use new techniques and modern inputs, whereas younger farmers, by virtue of their greater opportunities of formal education, may be more skillful in their search for information and the application of new techniques (Hussain, 1989). This could mean that younger farmers have relatively better capacity to manage their farm land which enables them to improve the level of their cereal crop productivity. This result may be supported by the result from the descriptive summary of the study as the age of the farmers ranged between 17 and 103 years with an average age of 51 years, implying that farmers under this study were relatively old, a condition that might have affected productivity negatively.

On the contrary the age-squared positively and statistically affected cereal crop productivity at the 10 per cent significance level, showing a U-shaped relationship between age and crop productivity. This suggests that age has a negative effect on crop productivity until a turning point is reached; beyond that value it has a positive impact. It also reveals that older household heads are more productive than younger ones. Results from previous studies such as Beniam et al., (2004), assume that the older a farmer gets, the more experienced he is. They argue that she/he will appear to be more productive than younger farmers due to good managerial skills, which he/she has learnt over time. Besides, given the importance and significance of land, labor, capital and other resources in agricultural crop production, it could be argued that young households are deficient in these resources and might not be able to apply inputs or implement certain agronomic practices sufficiently quickly. In sum, a possible explanation for these two contrasting effects regarding the age of household head might have neutralized each other in such a way that the older and hence more experienced farmers have more knowledge about their farm lands and traditional practices of agricultural crop production, but are less responsive to new ideas. Consequently this might have a negative effect on their crop productivity.

Weather variations' effects on yield

The effect of weather variables' variability specified in the study is as anticipated as climate related variables significantly affected cereal crop productivity in the analysis. Coefficients from random-effects and fixed-effects models, both in linear and squared terms, annually and seasonally revealed that cereal crop productivity was generally sensitive to climate variables. The results reveal that most of the squared terms of weather variables were significant annually and seasonally at the 1 per cent significance level, implying that climate had a non-linear effect on cereal crop productivity. When the quadratic terms are negative, the crop productivity function has a U-shape and will have an inverted U-shape when the quadratic term is positive. This shows that there is a known amount and time range of temperature and precipitation in which a crop grows best across the seasons and/or annually, although optimal weather factors vary from crop to crop (Mendelsohn et al., 1994). For example, in this paper it was hypothesized that peak mean rainfall influences crop productivity positively, that is, more rainfall increases productivity of cereal crops. Expectedly, the results show that an increase in precipitation, particularly for annual mean rainfall, has a positive effect on crop productivity. However, this is up to a point and then production (hence productively) starts declining as shown by the coefficient of the squared term of annual rainfall. Similar explanations hold for other climate variables' results.

The results for precipitation variables show that average annual rainfall affected crop productivity positively and significantly at the 1 per cent level, while its squared term had a negative effect significantly at the 1 per cent level. The negative sign of the coefficient of the squared term of annual rainfall shows that the average annual rainfall has a U-shaped relationship with cereal crop productivity, that is, as rainfall increases, cereal crop productivity decreases but up to a certain point and then it starts increasing. This means, annual rainfall has a negative effect on cereal crops until a turning point is reached but beyond that value rainfall has a positive impact. The coefficient of the linear term suggests that if rainfall is favorable (in terms of timeliness, amount and distribution), then households experience a relatively better crop productivity condition. The result may be due to the fact that rainfall enhances crop productivity as it improves the soil's capacity and enables it to use the fertilizers and other inputs effectively (Tchale and Suaer, 2007). Its calculated elasticity suggests that any increase in average annual precipitation by 1 mm will increase cereal crop productivity levels by more than 2.5 per cent. Interpreting the result the other way round a decrease in average annual precipitation by 1 per cent annually would lead to a decrease in cereal crop yields by 2.5 per cent.

Analyzing the regression results seasonally shows that precipitation during the spring season affected cereal crop productivity negatively and significantly at the 1 per cent level. Similarly summer and fall seasons' average precipitation variability affected cereal crop productivity negatively but insignificantly. The decrease in crop productivity per hectare with increasing summer precipitation indicates that the existing current level of precipitation is enough for planting. The reduction in crop productivity per hectare with an increase in precipitation during the fall season (September, October and November) - the period commonly known as the harvesting season in the study area -- is due to crops' reduced water requirements and consequently more precipitation damages crops (Deressa et al., 2008) during the harvesting season.

Contrary to the average annual precipitation variable, the average annual temperature variable associated negatively to cereal crop productivity reflecting that average annual temperature had a negative effect on crop yields. Moreover, estimated coefficients for the temperature variable were found to have large values implying the temperature variables' variation to have a large impact on cereal crop productivity. The results show that the coefficients of annual and summer season temperatures are negative and significant at 1 per cent; while their square terms have a positive effect on crop productivity significantly at the 1 per cent level. The coefficient of the squared term of annual temperature is positive showing that the annual temperature has an inverted U-shaped relationship with cereal crop productivity, that is, as temperature increases, cereal crop productivity increases but up to a certain point and then it starts declining. This means, annual temperature has a positive effect on cereal crops until a turning point is reached and beyond that value the temperature has a negative impact. Concerning linear terms, the results suggest that an increase in mean annual temperature reduces crop productivity per hectare. The result is in line with that of Schlenkeret et al. (2006) who showed that the extreme end in average annual temperature distribution is always harmful for crop growth, irrespective of the type of crop. The elasticity value indicates that a 1^{o}C increase in average annual temperature could reduce cereal crop productivity levels by 27.23 per cent. This may be due to increase (downward move) in average annual minimum temperature or (upward move) in average annual maximum temperature during the crop growing season which in turn leads to a decline in cereal crop productivity.

Analyzing the results seasonally shows that the coefficients of mean average temperature during fall and spring seasons affected cereal crop productivity which was positively significant at the 1 per cent while the squared terms had a negative effect significantly at the 1 per cent level. However, increase in temperature during the summer season related to cereal crop productivity negatively while its squared term related in an opposite manner significantly at the 1 per cent level. The results suggest that an increase in temperatures enhances crop productivity per hectare during fall and spring seasons. Their elasticities indicate that when the fall and spring temperature increased by 1 per cent or 1°C, crop production and thus productivity increased by 20.142 and 17.772 per cent respectively. During the short rainy season, the spring season, a slight increase in temperature with the same level of precipitation enhanced germination as the season is well-known as the planting period in Ethiopia. During the fall season, a higher temperature was beneficial for harvesting. It is important to notice that most crops have finished their growing period by autumn, and a higher temperature quickly dries up the crops and facilitates harvesting so it has a positive effect on crop productivity (Mendelsohn and Dinar, 2003). In general these findings confirm the notion that climate variability is one of the critical 'drivers of crop productivity' in many African agrarian households (the World Bank, 2006).

Marginal impact analysis of weather variables

Further, considering linear and squared terms, the climate coefficients reveal that agricultural crop productivity is generally sensitive to climate variables. However, the effect of quadratic weather variables on crop productivity is not obviously determined simply by looking at the coefficients. This is due to the fact that both the linear and the squared terms play a role; rather the weather variables could be interpreted based on the marginal effects or elasticities of weather variables (Kurukulasuriya and Mendelssohn, 2008). This is important in order to observe the overall effect of an infinitesimal change in temperature and rainfall on cereal farming, and for avoiding complexity of the analysis and interpretations due to squared terms.

Following Lee et al., (2012) and Gebreegziabher et al., (2013), denoting weather variables as W, one can derive the marginal impacts (elasticities in our case) of weather variables (W_i) on cereal crop productivity evaluated at the mean of that variable:

$$(7) \qquad E\left[\frac{dY}{dW_i}\right] = E\left(\beta_{1i} + 2\beta_{2i}W_i\right) * E\left(W_i\right) = \left(\beta_{1i} + 2\beta_{2i}E(W_i)\right) * E\left(W_i\right) = \left(\beta_{1i} + 2\beta_{2i}\overline{W_i}\right) * \overline{W_i}$$

where E is the expectations operator; β_{1i} are the semi-elasticities of the linear term and β_{2i} are the semi-elasticities of the quadratic term of the corresponding weather variables. $E\left(W_i\right) = \overline{W_i}$, are mean values of the corresponding weather variable (Table 6).

Table 6: Calculated elasticities/marginal effect of climate variables on cereal crop productivity

Weather Variables	Annual	Summer Season	Fall Season	Spring Season
Precipitation	1.686***	-0.576	-0.041	-0.326***
Temperature	-23.330***	-8.953***	17.098***	14.476***

Note: *** $p < 0.001$.

Table 6 calculates elasticities of seasonal and annual weather variables which show effects of increases in temperature by 1°C and increases in precipitation by 1 mm per season and annually on cereal crop productivity. The elasticity of annual precipitation indicates that a 1mm increase in annual precipitation will have a positive effect on cereal crop productivity and will hence lead to an increase in crop productivity while seasonal precipitation will have a negative effect on cereal crop productivity leading to a decrease in crop productivity. On the other hand, an increase in average annual and summer season temperature decreases cereal crop productivity while an increase in temperature during the fall and spring seasons increases cereal crop productivity. Marginally, their calculated elasticities suggest that any increase in average annual precipitation by 1mm will increase cereal crop productivity levels by 1.686 per cent. Interpreting the result the other way round a decrease in average annual precipitation by 1 per cent annually will lead to a decrease in cereal crop yields by 1.686 per cent; while a 1mm increase in precipitation during the spring season will lead to a decline in crop productivity by 0.326 per cent. The elasticities of temperature variables indicate that a 1°C increase in annual and summer temperatures could lead to a decrease in crop productivity levels by 23.330 and 8.953 per cent respectively, while a 1 per cent or 1°C increase in fall and spring season temperatures will lead to an increase in crop production and thus an increase in cereal crop productivity by 17.098 and 14.476 per cent respectively.

As expected, geographical differences were included in the regression analysis as a set of regional dummy variables – the agro-climatic zones (ACZ) -- to represent time-persistent agro-climatic or regional differences which affect cereal crop productivity positively and significantly at the 1 per cent level. It appears that farming in midland or highland areas as compared to lowland areas contributed to cereal crops' productivity increasing. This points to the importance of location-specific determinants of cereal crop productivity, with households in highland ACZs demonstrating higher cereal crop productivity as compared to households in lowland ACZs. For instance, the coefficient of a dummy variable highland ACZ is higher than that of a lowland ACZ, indicating that the production in highland ACZs is relatively superior to that in lowlands. Hence, in line with descriptive results, the corresponding computed coefficients show that crop yields increase in highland areas by 169.11 per cent; and also increase in midland areas by 13.364 per cent. Thus regression models indicate that households in higher ACZs tend to be more productive. Therefore, more production with better productivity is likely to be at higher altitudes where rainfall and temperature are favorable for cereal crop production.

Lastly, the results for the time/trend variable --- a proxy variable for technical change in crop production -- positively and significantly impacted crop productivity at the 1 per cent level. The positive sign shows that there is technological regress or upward shift in production between these time periods. The regression coefficient gives evidence that there has been an increase in cereal crop productivity by 7.8 per cent over the past 15 years. This shows that cereal crop productivity increased in the panel, implying that there were technical improvements among Ethiopian farmers during 1999 and 2014.

5. CONCLUSION AND RECOMMENDATIONS

A large body of literature demonstrates negative impacts of climate change and climate variations on crop production and productivity. In particular, as climate change is likely to intensify high temperatures and low precipitation, its most dramatic impacts will be felt by smallholder and subsistence farmers. Considering Ethiopian agricultural crop production it is observed that while for a majority of the cereal crops the productivity increase is due to increased use of physical inputs and governmental support, the gradual increase in annual and seasonal climatic factors in the last few decades has had a measurable effect on Ethiopian cereal crop productivity. In this paper we evaluated the impacts of climatic and non-climatic factors on cereal crop productivity and provided a descriptive and econometrics analysis of the impacts of these factors on Ethiopian cereal crop productivity using four rounds of surveyed panel datasets collected from randomly selected rural farm households covering the period from 1999 to 2014. Consistent with previous findings of productivity studies in sub-Saharan Africa, which primarily consider conventional agricultural production inputs and climate factors, the results of our regression analysis confirm the importance and statistically strong dependence between most of the explanatory variables and cereal crop yields in Ethiopia.

Descriptive results show that cereal crop production and productivity increased over the period in the study area and in each ACZ. In the study area average annual and seasonal rainfall distribution declined, while average annual and seasonal temperatures increased through the study period. However, the trend of annual and seasonal weather variables was not uniform in agro-ecological zones. Econometrics models' results indicate that inputs such as use of agro-chemicals, livestock ownership measured in TLUs, the number of plots on which cereal crops were cultivated and participation of the farmers in government agricultural extension services significantly enhanced cereal crop productivity levels. On the other hand, cereal sown farm land size (area in hectors), household head's age and educational level influenced cereal crop productivity negatively and significantly. Considering first order and squared terms of the weather variables included in the model specification, the regression results reveal that cereal crop productivity is generally sensitive to climate variables. Furthermore, estimates from the models both for the first order and squared term of weather variables - temperature and rainfall both annually and seasonally -- were found to be significant determinants of cereal crop productivity, implying that climate has a non-linear effect on cereal crop productivity.

Average annual rainfall affected cereal crop productivity positively and significantly; while its square term had a positive effect significantly at the 1 per cent level. Its linear coefficient suggests that any increase in average annual rainfall (precipitation) by 1mm will increase cereal crop productivity levels by more than 0.825 per cent. Interpreting the results the other way round a decrease in average annual precipitation by 1 per cent annually will lead to a decrease in cereal crop yields by 0.825 per cent. Average precipitation during the spring season affected cereal crop productivity negatively and significantly; while the summer and fall seasons' mean rainfall affected cereal crop productivity negatively. On the other hand, annual temperature averages affected cereal crop productivity negatively; while its square term had a positive effect significantly at the 1 per cent level of significance. Its linear coefficient suggests that a 1^{o}C increase in average annual temperature could reduce cereal crop productivity levels by 27.235 per cent. This may be due to increase (downward move) in average annual minimum temperature or (upward move) in average annual maximum temperature during the crop growing season which in turn leads to a decline in cereal crop productivity. This negative impact would probably become worse with accelerating climate changes in the future. Further, first order term temperature variables during fall and spring seasons affected cereal crop productivity positively while their squared terms were related to cereal crop productivity positively and all were statistically significant at the 1 per cent level, suggesting that an increase in temperatures enhances crop productivity per hectare during fall and spring seasons. However, an increase in temperature during the summer season was found to be negatively associated with cereal crop productivity while its squared term was related positively and significantly at the 1 per cent level. This suggests a decreasing return but at an increasing rate.

Moreover, in line with the descriptive results the regression results also show that as expected geographical differences included in the regression analysis as a set of regional dummy variables considerably affected cereal productivity significantly. Its statistical significance points to the importance of location-specific determinants of cereal crop productivity, with households in highland ACZs demonstrating a higher position compared to households in lowland ACZs in producing cereal crops. Therefore, more productive production is likely to be in higher altitudes where rainfall and temperature are favorable for cereal crop production. Lastly, the time/trend variable is also positively and statistically significant showing there was technological regress or upward shift in cereal crop productivity over the period of study. These outcomes are important and can be used to inform the government on possible policy decisions, such as where to emphasize when planning on climate change adaptation strategies to be promoted and ways to envisage better provision of extension services that are tailored to the peculiarities of the ACZs across the country. Thus the study's results confirm that weather change effects (expressed as rainfall decline and rise in minimum-maximum temperature) contribute to increased inefficiency in agricultural crop yields in Ethiopia and in the study areas. The study therefore recommends public policies geared at improving agricultural extension services, farmers' education, supply of agricultural production inputs and developing climate change adaptation strategies suitable for the different agro-ecological zones.

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