

Review on the Impact of Climate Change on Crop Production in Ethiopia

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Abstract
This paper reviews the impact of climate change on crop production in Ethiopia. The rainfall variability has significant and negative impact on outputs of crop agriculture in Ethiopia. When the annual rainfall diverges from its mean (both upward and downward), the level of production of all crop types diminished significantly. When there is extreme rainfall, the impact of fertilizer to boost productivity has diminished. This paper also reviews recent literature concerning a wide range of processes through which climate change could potentially impact global-scale agricultural productivity, and presents projections of changes in relevant meteorological, hydrological and plant physiological quantities from a climate model ensemble to illustrate key areas of uncertainty. Few global-scale assessments have been carried out, and these are limited in their ability to capture the uncertainty in climate projections, and omit potentially important aspects such as extreme events and changes in pests and diseases. The dependence of some regional agriculture on remote rainfall, snow melt and glaciers adds to the complexity. Indirect impacts via sea-level rise, storms and diseases have not been quantified. Perhaps most seriously, there is high uncertainty in the extent to which the direct effects of CO_2 rise on plant physiology will interact with climate change in affecting productivity. At present, the aggregate impacts of climate change on global-scale agricultural productivity cannot be reliably quantified. Other factors such as area, demand for crop production (private consumption) and labor force have affected crop production significantly. Since climate change is an inevitable phenomenon, policy makers should introduce adaptation measures to sustain the economic growth observed in the last few years.
Keywords: agricultural productivity, climate change, crop production, rain fall variability

1. Introduction

The global climate change and the associated weather extremes continued posing considerable challenge both on developed and developing countries. Climate induced food shortages and chronic diseases affected billions of people in developing countries (IPCC, 2007).

Although climate has mainly affected developing countries, the developed countries have not also been immune from its devastating impact either. The recent tsunami in Japan that claimed more than 27 thousand lives and lost an estimated of 235 billion dollars, the earthquake that killed more than 70,000 people in Sichuan province of China, the hurricane Katrina in the US that lost more than 40 billion dollar and more than 10,000 lives, the Indian Ocean tsunami in 2004 that caused some 250,000 deaths are some but few manifestations of anomalies of climate change in the developed world (Mendelsohn and Tiwari, 2010).

Though climate change poses devastating impacts in both developed and developing countries, the developed world are not committing their pledges to reduce GHG emission, however. As a result, fixing the global temperature below 2^{o}C by 2020 is less likely to be achieved in the years to come (IPCC, 2007).

Ethiopia is one of the most vulnerable countries to climate variability. The agriculture sector which contributes more than 45% of GDP, 80% to labor force and 85% to foreign exchange earnings is highly susceptible to climate change. More than 95% of crop production which is rainfall dependent has been produced by small holders and subsistent farmers who have less capacity to adaptation of climate change (MoFED, 2006).

On the other hand, Ethiopia's contribution to the global green house gases emission (GHG) is limited due to its lower economic activity. Climate change affects the production and productivity of the crop sector by decreasing soil fertility, increasing pests and crop diseases and aggravating lack of access to inputs and improved seeds and frequent drought and floods due to low irrigation scheme, poverty, high population pressure, lack of institutional capacity to adaptation (Assefa *et al*., 2006; Mahmud *et al*., 2008).

Like any other developing countries, Ethiopia has two independent options to respond to climate change mitigation and adaptation. Given the low level of industry sector, mitigation would not suit to Ethiopia for it deters the growth spurs that has registered in the last few years. Instead, adaptation measures such as use of different crop varieties, tree planting, soil conservation, early and late planting, and use of irrigation should be taken by farmers to adapt to climate change (Temesgen *et al*., 2008).Therefore, the objective of the study is to asses and review the major impacts of climate change on crop production in Ethiopia.

2. Evolution of Climate Change

According to the Inter-governmental Panel on Climate, there is an equivocal agreement on the warming of the global system. The average air and ocean temperature has increased, the snows and ices have been melted, and the global average sea level has risen (Cline, 2007). The following figure shows the globe air temperature was on average warmer by 0.2°C in 2001-2010 than the 1991-2000 decade.

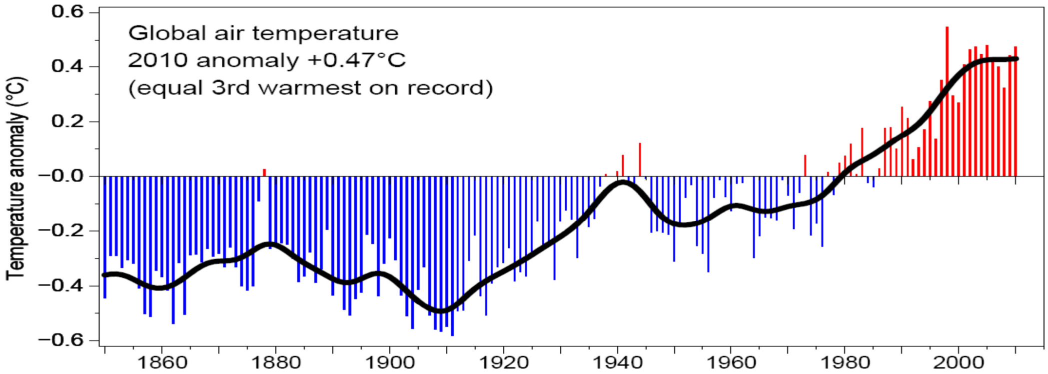

Figure 1. Trend of global air temperature
Source**:** (Assefa *et al*., 2006)

When we come to Ethiopian case, annual temperature has rapidly increased in the last five decades. The mean annual temperature rose by 1.3°C or by 0.28 °C per decade during 1960-2006. The frequencies of hot days and nights have also showed an increasing trend during these years. While the average number of 'cold days' has decreased by 5.8% between1960-2003, the average number of 'cold' nights per years has decreased by 11.2% (UNDP, 2008). In the coming 100 years, the average temperature in Ethiopia has projected to increase from 23.08 °C during 1961-1990 to 26.92°C in 2070-2099 (World Bank, 2008). However, significant temperature difference is there among different parts of the country. While highlands in the Central North of the country will be as cold as -0.5°C, the Southeast low lands will be as warms as 37°C. These extreme temperatures constrain crop production by limiting water availability and growth of many plants (Temesgen *et al*., 2007).

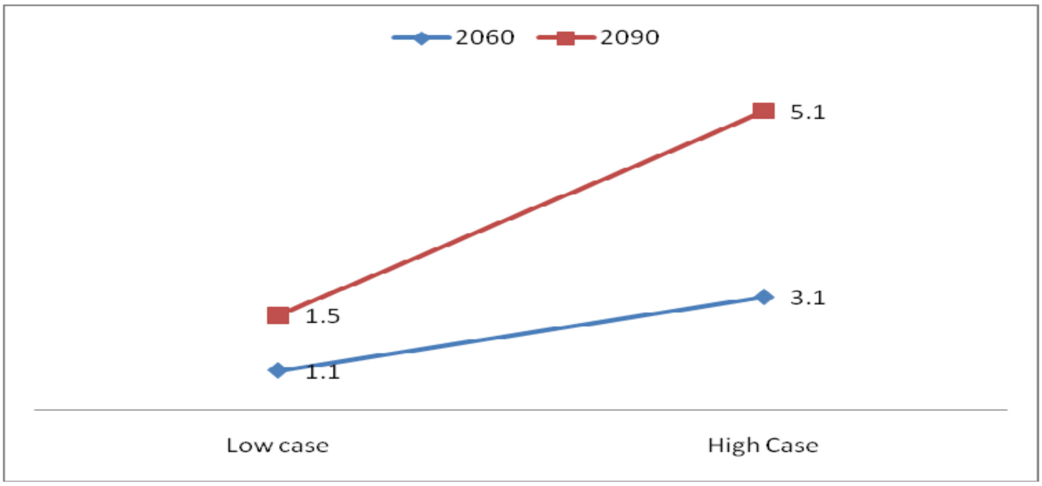

Figure 2. Evolution of Average Temperature in Ethiopia
Source: (World Bank, 2008)

The mean annual temperature is projected to increase by 1.1 - 3.1°C in the 2060s and by 1.5-5.1°C in the 2090s. All projections indicate substantial increase in the frequency of days and nights that are considered 'hot' in current climate. All projections indicate decreases the frequency of days and nights that are considered 'cold' in the current climate.

Looking at the precipitation; there is inter-annual and inter-decadal rainfall variability in Ethiopia. Geographical location and topography leads the country to be vulnerable to rainfall variability. The strong inter-annual and inter-decadal variability in rainfall makers difficult to detect long term trends in the country. There is not statistically significant trend in observed mean rainfall in any season between1960-2006. Rainfall variability is the major source of risk for farmers who depend on crop production. There are two important rains in Ethiopia- the 'Kiremt' and 'belge'. The Kiremt rains usually begin in March and May in South West and advancing northwards affecting most of the country from July through September. The kiremt rain constitutes about 90% of the crop production harvested during October–December (CSA, 2011). Historically the country has been prone to extreme weather variability. Major droughts that led to dreadful famines and floods struck different parts of the country (World Bank, 2006).

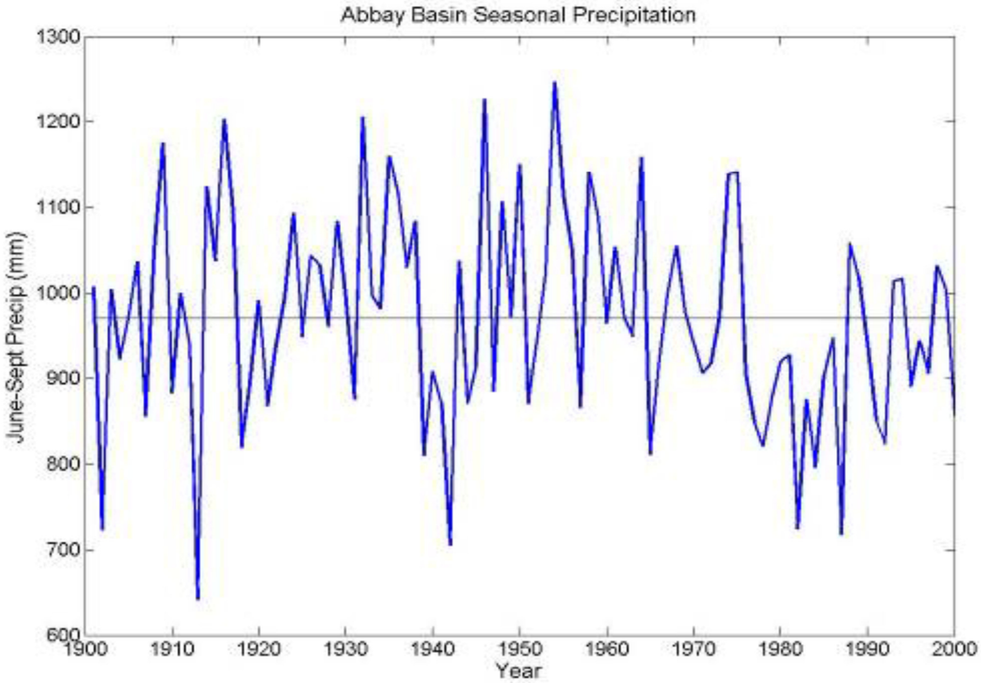

Figure 3. Seasonal precipitation in Ethiopia
Source: (Assefa *et al*., 2006)

Climate change reduced yield of wheat staple by 33% in Ethiopia (World Bank, 2006). It also exacerbated the transient poverty. Poverty rates would have been decreased by 14% if the recurrent drought did not happen (UNDP, 2008). Climate change also cause encroachment of malaria from lower altitude to higher altitude. An epidemic of cholera following the extreme floods led to widespread loss of life and illness (NAPA, 2007).

At country level, the average precipitation rate has been 2.04 mm per day in 1961-1990. This precipitation is projected to decrease to 1.97 mm between 2070–2099 (Cline, 2007). The problem is exacerbated by higher evaporation rates associated with increasing temperature. Precipitation rate like the temperature is expected to vary between different parts of the country. While it will be decreasing in the northern, the southern part of the country would see an increase of temperature as much as 20%.

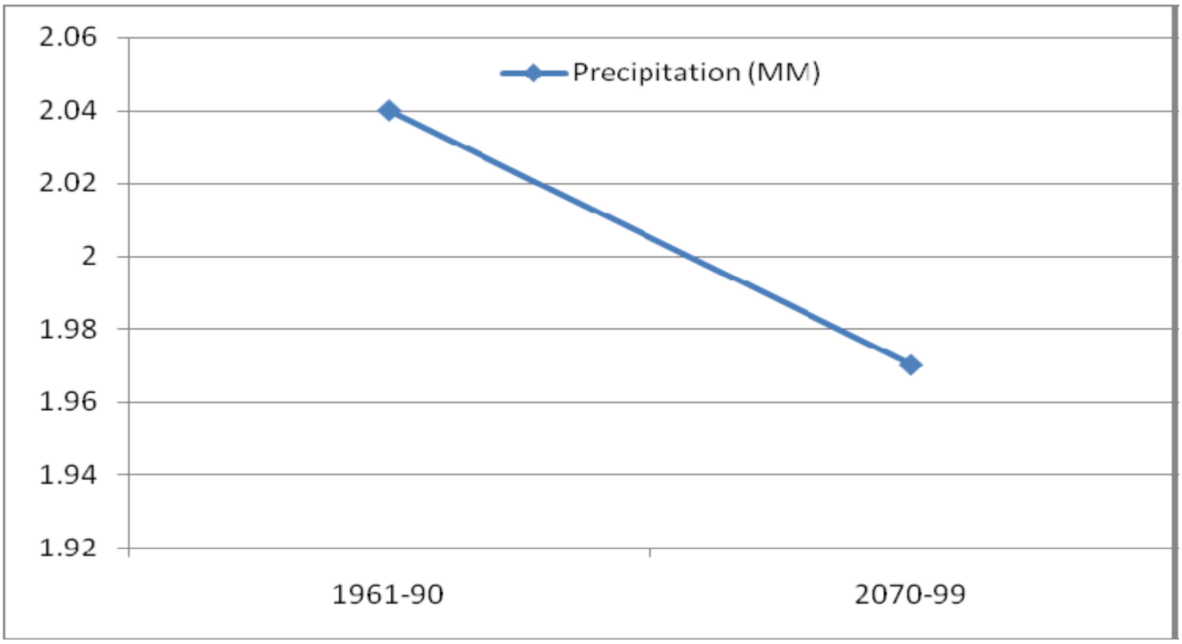

Figure 4. Precipitation rate over the coming 100 years
Source: (World Bank, 2008)

The rainfall variability measured by the coefficient of variation is common in Ethiopia as Figure 5 shows. According to Agricultural economists, rainfall variability greater than 30 is risky for farmers who depend on crop production which is prevalent in most parts of Ethiopia (NAPA, 2007). Annual rainfall considerably decreases towards the eastern low lands which is source of low crop production. Rainfall is distributed differently in Ethiopia. It has both spatial and seasonal nature as the following figure shows. Few highlands in the West get rainfall for most of the months of the year (May-October). Rainfall variability measured by coefficient of variation shows most part of the country has rainfall variability with about 31-50 (Figure 5).

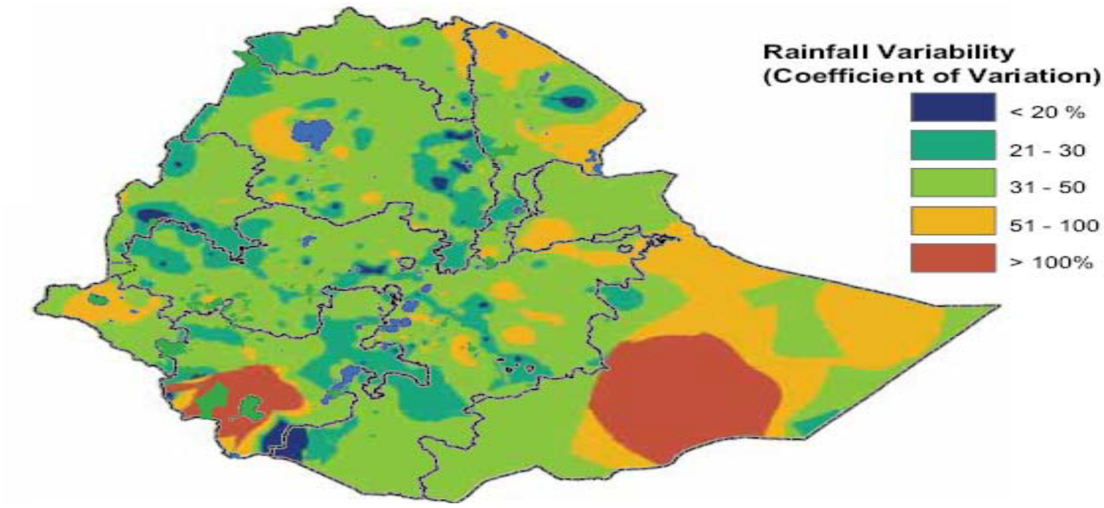

Figure 5. Rainfall Variability in Ethiopia
Source: (NAPA, 2007)

3. Direct Impacts of Climate Change on Agriculture
3.1. Changes in Mean Climate

The nature of agriculture and farming practices in any particular location are strongly influenced by the long-term mean climate state the experience and infrastructure of local farming communities are generally appropriate to particular types of farming and to a particular group of crops which are known to be productive under the current climate. Changes in the mean climate away from current states may require adjustments to current practices in order to maintain productivity, and in some cases the optimum type of farming may change. Higher growing season temperatures can significantly impact agricultural productivity, farm incomes and food security (Battisti and Naylor, 2009). In mid and high latitudes, the suitability and productivity of crops are projected to increase and extend northwards; especially for cereals and cool season seed crops (Maracchi *et al*., 2005; Tuck *et al*. 2006; Olesen, 2007). Water is vital to plant growth, so varying precipitation patterns have a significant impact on agriculture. As over 80 per cent of total agriculture is rain-fed, projections of future precipitation changes often influence the magnitude and direction of climate impacts on crop production (Olesen and Bindi, 2002; Tubiello *et al*., 2002; Reilly, 2003).

3.2. Climate Variability and Extreme Weather Events

While change in long-term mean climate will have significance for global food production and may require ongoing adaptation, greater risks to food security may be posed by changes in year-to-year variability and extreme weather events. Historically, many of the largest falls in crop productivity have been attributed to anomalously low precipitation events (Kumar *et al*., 2004; Sivakumar *et al*., 2005). However, even small changes in mean annual rainfall can impact on productivity. As current farming systems are highly adapted to local climate, growing suitable crops and varieties, the definition of what constitutes extreme weather depends on geographical location. In many regions, farming may adapt to increases in extreme temperature events by moving to practices already used in warmer climate, for example by growing more tolerant crops. However, in regions farming exists at the edge of key thresholds increases in extreme temperatures or drought may move the local climate into a state outside historical human experience. In these cases it is difficult to assess the extent to which adaptation will be possible (Salvatore *et al*., 2010).

3.2.1. Extreme Temperatures

Changes in short-term temperature extremes can be critical, especially if they coincide with key stages of development. Only a few days of extreme temperature (greater than 32^{o}C) at the flowering stage of many crops can drastically reduce yield (Wheeler *et al*., 2000). Crop responses to changes in growing conditions can be nonlinear, exhibit threshold responses and are subject to combinations of stress factors that affect their growth, development and eventual yield. In the short-term high temperatures can affect enzyme reactions and gene expression. In the long-term these will impact on carbon assimilation and thus growth rates and eventual yield.

3.2.2. Drought

There are a number of definitions of drought, which generally reflect different perspectives (Holton *et al*., 2003). It is common to distinguish between meteorological drought (broadly defined by low precipitation), agricultural drought (deficiency in soil moisture, increased plant water stress), hydrological drought (reduced stream flow) and socio-economic drought (balance of supply and demand of water to society).

3.2.3. Heavy Rainfall and Flooding

Crop production can also be impacted by too much water. Heavy rainfall events leading to flooding can wipe out entire crops over wide areas, and excess water can also lead to other impacts including soil water logging, anaerobicity and reduced plant growth. Indirect impacts include delayed farming operations (Kettlewell *et al*., 1999).

4. Indirect Impacts of Climate Change on Agricultural Productivity

4.1. Pests and Diseases

Rising atmospheric CO_2 and climate change may also impact indirectly on crops through effects on pests and disease. These interactions are complex and as yet the full implications in terms of crop yield are uncertain. Indications suggest that pests, such as aphids (Newman, 2004) and weevil larvae (Staley and Johnson, 2008), respond positively to elevate CO_2. Increased temperatures also reduced the overwintering mortality of aphids enabling earlier and potentially more widespread dispersion (Zhou *et al*., 1995). Evidence suggests that in sub-Saharan Africa migration patterns of locusts may be influenced by rainfall patterns (Cheke and Tratalos, 2007) and thus potential exists for climate change to shape the impacts of this devastating pest. Pathogens and disease may also be affected by a changing climate. This may be through impacts of warming or drought on the resistance of crops to specific diseases and through the increased pathogen city of organisms by mutation induced by environmental stress (Gregory *et al*., 2009). Over the next 10–20 years, disease affecting oilseed rape could increase in severity within its existing range as well as spread to more northern regions where at present it is not observed (Evans *et al*., 2008). Changes in climate variability may also be significant, affecting the predictability and amplitude of outbreaks.

4.2. Mean Sea-Level Rise

Sea-level rise is an inevitable consequence of a warming climate owing to a combination of thermal expansion of the existing mass of ocean water and addition of extra water owing to the melting of land ice (Pfeffer *et al.*, 2008). This can be expected to eventually cause inundation of coastal land, especially where the capacity for introduction or modification of sea defenses is relatively low or non-existent. Regarding crop productivity, vulnerability is clearly greatest where large sea-level rise occurs in conjunction with low-lying coastal agriculture. Many major river deltas provide important agricultural land owing to the fertility of fluvial soils, and many small island states are also low-lying. Increases in mean sea level threaten to inundate agricultural lands and salinize groundwater in the coming decades to centuries, although the largest impacts may not be seen for many centuries owing to the time required to melt large ice sheets and for warming to penetrate into the deep ocean.

5. Vulnerable Groups to Climate Change in Ethiopia

According to Assefa *et al*. (2006), small- scale, rain fed, subsistence farmers and pastoralists are the most vulnerable groups to climate changes in Ethiopia. They also indicated that climate change impacted regions differently. Regions with arid, semi-arid, and dry sub humid low lands are more vulnerable but low lands have been found less vulnerable to climate change. Diversification of livelihoods, migration, nonfarm activities, and sales of assets, settlement and resettlement activities, and the adoption of improved water management system are few measures that have been taken by households to the impact of climate change.

Similarly, Mahmud *et al*. (2008) have studied the different impact of climate change adaptation on food production. Farm households who have adapted to climate change have better food production level than farm households that did otherwise. According to them significant share of farmers perceived the mean temperature of Ethiopia has increased over the past 20 years. Thus farmers has taken a number of adaptation measures including changing crop varieties, adapting soil and water conservation measures, harvesting water and planning trees and changing planting and harvesting periods. Access to information to future change in climate change, access to agricultural extension and credit services are determinants that made difference on farmers to take adaptation measures (Mahmud *et al*., 2008).

According to World Bank's climate projections model, global warming leads to rainfall variability with a rising frequency of both severe flooding and droughts. Economy-wide impacts of climate change studied by the World Bank indicated that the GDP losses are significant. The model highlights the high degree of vulnerability of Ethiopian agriculture and infrastructure to the climate shocks of the future. Climate change brings about increased weather variability, which translates into large swings in the growth rate of agricultural GDP (World Bank, 2006).

6. Polices on Climate Change in Ethiopia

According to MoFED (2010), policy makers play an important role to reduce climate change. Recently, many countries are mainstreaming climate change in to their development plans. The Ethiopian energy policy address issues pertaining to climate change. The policy has been approved in 1997 before climate change has got high priority on the international agenda. It commends that the current population to use resources without compromising the survival of future generation. Ethiopia's share to global GHG emission is very minimal. However, emissions from agriculture and energy sectors double since 1994. These two sectors are the major emitters in Ethiopia accounting for 85% and 15% of the total gas emission respectively. This shows that there is high potential for mitigation through these sectors. Clean Development mechanisms (CDM) measures from agriculture and hydroelectric plants, geothermal and wind turbine, conservation of energy through efficient and switching energy sources, usage of compact and efficient vehicles, changing means of transport to fuel efficient modes of transport and usage of efficient stoves are some of the strategic directions that the government promoted in its policy documents. These directions are consistent with the United Nations Framework Convention on Climate Change (UNFCCC) recommendations (MoFED, 2010).

In addition, the Ethiopian government gives emphasis to climate change adaptation and mitigation in the five years development plan (GTP). The Plan embodied climate change issues to make national development paths more sustainable as compared to the previous Plans. Although it's difficult to evaluate the effectiveness of the plan in terms of implementation at this stage, the plan gives due emphasis to the construction of hydroelectric dams and medium to large scale irrigation schemes, and the development of other renewable energy sources like wind, solar and bio-fuel (FDREMWR, 2007).

Although Ethiopia has abundant water resources and hydroelectric potential, capacity only less than 5% of water has been developed for irrigation. In addition only less than 5% of the Nile basin was employed for irrigation development. That lead that the per capita electricity to be the least in the world with more than 80% of the population living without access to electricity and relying on firewood, charcoal, dung, kerosene, gas and bio-gas which are major sources of high CO_2 emission.

For the first time in its history, the construction of large scale dam with about an installed capacity of 5225 MW has been introduced in the Blue Nile River. This project has also a potential to develop more than 35% or 250,000 hectare land around Nile River. However, this time the irrigation part seems overlooked by the government to focus on the electricity generation. The implementation of this project will have many financial, political and institutional challenges, however. More than anything else, climate variables could be big challenges to fill the dam in a way that could not affect the downstream flow. If the project realized passing all the inside and outside changes, it will end the historic dominance of Egypt and Sudan on Nile water. In return, the supply of energy in Ethiopia from renewable sources will reach 10,000MW at the end of 2014/15.

These hydroelectric projects will have a potential to realize the ongoing rural electrification access program and increase the electric power supply coverage at country level from existing 41% to 75% coverage at the end of the plan period. This will make the country's green development strategy consistent with the global green development strategy (MoFED, 2010).

To decease the impact of the short term weather variation, the GTP promises to use the water resources properly through expansion of small scale irrigation. Thus if the plan is rightly implemented it would reduce the negative impact of climate change on production and productivity of crops. Further, the government promises to achieve the 7th Goal of the MDG the latest by 2015. The main target of the goal is to ensuring environmental sustainability through different indicators including integrating the principles of sustainable development into the country's policies and programs; reverse loss of environmental resources; reducing biodiversity loss; reducing people without sustainable access to safe drinking water and basic sanitation, and improving the lives of slum dwellers.

7. Adapting to Climate Change: The Role of Agricultural Research

There are many ways in which agricultural and natural resource management research and development (R&D) can contribute to climate change adaptation. For the sake of this paper, however, only four R&D areas will be considered: improved crop varieties, soil and water conservation, agroforestry, and the use of seasonal climate forecasting to strengthen agriculture.

7.1. Drought Mitigation through Plant Breeding

Drought has always been a great limiting factor to agricultural development in sub-Saharan Africa, particularly in East Africa. The International Centre for Maize and Wheat Improvement (CIMMYT) has initiated important projects to develop and distribute maize varieties that are able to yield more than the currently available cultivars under conditions of limiting moisture, low fertility and disease or pest pressure while bearing no yield penalty under optimal conditions (CIMMYT, 2004).

7.2. The Role of Rain Water Harvesting

Land degradation has a magnifying effect on climate extremes. In many areas of Africa, a very small proportion of rainwater is used by crops, the remaining being lost through runoff and deep percolation. Therefore, since climate change is likely to result in reduced or erratic rainfall over large areas of East Africa, techniques that can improve rainwater infiltration or its storage for immediate or future use by crops or livestock are increasingly needed. Rainwater harvesting (RWH) is defined as a method for inducing, collecting, storing and conserving local surface runoff for agriculture in arid and semi-arid regions (Hatibu and Mahoo, 2000).

7.3. The Role of Agroforestry

The role of agroforestry in sequestering carbon and contributing to climate change mitigation is well documented (Maracchi *et al*., 2005). What is less understood is its potential for mitigating the negative effects of climate variability and climate change. Agroforestry provides a rich set of promising technologies that can (biophysically and economically) buffer against current climate variability and food or income risks (Table 1).

Table 1. Agroforestry options for climate change adaptation

Agroforestry technology	Relationship with climate change adaptation
Trees on farm	Microclimate for reducing heat stress; tree products to buffer against crop failure.
Boundary planting	Fencing for allowing off-season farming; microclimate effect; erosion control.
Rotational woodlot	Soil fertility; erosion control; better water infiltration.
Improved fallows	Increase water infiltration and holding capacity of soils; reduce weeds that compete with crops for Water; mitigate dry spells/ drought; reduce soil temperatures through mulching.
Fodder bank	Mitigation of drought-caused fodder shortages.
Domestication of indigenous trees	Economic buffer through production of high value products (fruits, wood, honey, resins, medicine, etc).

Source: (Maracchi *et al*., 2005)

8. Estimating the Impact of Climate Change on Agriculture

There are several ways to estimate the impact of climate change on agriculture. The data used in this study comes from secondary sources including CSA, MoFED, National Bank. The sample size of the data ranges from 1970-2010(Table 2). Crop is the major staple food, foreign exchange earner and source of income for the majority of the people in Ethiopia. Cereals, the principal staple food has a share of more than 80% of area and 86% of crop production. More than 12 million private peasant holders have engaged in the production of crop agriculture (World Bank, 2008; CSA, 2011). Overall, the crop sector after showing sluggish growth during 1975-1992 has showed remarkable growth in terms of production and area covered in the last two decades. However, when we look at the productivity of the sector though the population and then demand for food has surged, it has showed a steady growth in the last two decades. Thus, the major production gain was due to area expansion which has serious implication on climate change and environmental susceptibility. This mismatch between population and productivity growth may be major cause for the skyrocketing food price in the local market in recent years.

Table 2. Area Production and Yield of Crops during 1970-2010

Major Crops	Area (Millions of Hectares)			Production (Millions of Hectares)			Yield (Quintal/Hectare)		
	1970-1974	1975-1992	1992-2010	1970-1974	1975-1992	1992-2010	1970-1974	1975-1992	1992-2010
Cereals	5.24	4.90	7.29	62.93	57.97	96.10	12.0	11.8	13.0
Oilseeds	0.98	0.80	1.22	9.77	7.96	11.35	10.0	9.8	9.2
Pulses	0.18	0.21	0.54	0.71	0.90	3.14	4.0	4.3	5.6
Coffee	na	na	0.40			2.65			6.7
Other crops	na	na	0.98			43.94			44.8

Source: (CSA, 2011); na= data not available

Although temperature was identified as major climatic variable which affects crop agriculture in Ethiopia, there is no consistent data in Ethiopia on this variable. Thus we used only rainfall variability as a proxy for climatic variability. We decompose the crop sub-sector in to cereals, pulses, oilseeds, coffee and other crops. Crop sector comprised about 2/3 of the agricultural GDP and 1/3 of the total GDP over the sample period (1970-2010). Cereals are non tradable food crops but pulses, oilseeds and coffee are tradable crops consumed both in domestic and international market.

9. Conclusions

Rainfall variability has significant and negative impact on outputs of crop agriculture in Ethiopia. What matters most in crop production is not per se the amount of rainfall but how that level diverges from the mean rainfall which is supposed to be the optimal level. When the rainfall diverge from the mean value (both upward and downward), the level of production has significantly diminished to all crop types unanimously. Other factors such as fertilizer, area, demand for crop production and labor force have significant impact in addition to rainfall variability in all crops. When rainfall diverges from its mean; fertilizer use has also a negative impact on crop production. This is may be because in case of dry or excess rainfall conditions, fertilizer adoption may burn seeds and increase the probability of crop failure.

Area covered by crop production has also been found to be the detrimental factor to crop production in Ethiopia having positive and significant impact on all crop production. This indicate that sustaining crop production by expanding area will not be sustainable for it will exacerbate land degradation and will create vicious circle of climate change and crop failure. Active labor force in agriculture has also positive and significant impact on crop production.

Private consumption which is proxy for demand for crop agriculture has been found to have positive impact on crop agriculture. Increasing demand for the non-agricultural produces has also the prices for agricultural produces in the past few years. This creates an incentive to farmers to produce more. However, the climate variability hampers the productivity of the sectors as the data show. This is especially true if there is demand for production and the price is continuously increasing. Overall, rainfall variability has significant and negative impact on all crop types across the board although the cofactors have varied impacts on each crop types based on the nature of the crops whether it is annual or perennial, drought resistant or drought prone and cash or food. To sustain the agricultural growth, government should play key role by creating awareness on how to adapt to climate change.

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