Impact of El Niño and La Niña on Agriculture in Ethiopia: Implications for El Niño and La Niña adaptation and food security in Ethiopia

Abadi Berhane[1], Teklay Tesfay Bezabih[2]

Aksum University, College of Agriculture, Department of Plant Sciences E-mail: aabay2003@gmail.com
P.O Box: 251314, Tel: 251932053603

Abstract

El Niño is warming of the sea surface temperature of the Pacific Ocean. Extreme flooding, drought, lack of potable water for livestock and domestic use, food insecurity and market imbalance are associated with El Niño and La Niña in Ethiopia. Drought following El Niño caused 50 to 90% crop failure, in the eastern parts of Ethiopia. El Niño episodes are detected using different statistical indices such as Oceanic Nino Index (ONI), Agricultural Stress Index System (ASIS) and the Southern Oscillation Index (SOI), with magnitude ranging from weak to strong. Identifying the El Niño and La Niña seasons it is very important to adopt suitable adaptation strategies, which can resolve and/or reduce the negative impacts. Early warning and immediate support to the impacted areas have been carried out to minimize risks from El Niño animal feed for livestock from other areas has been transported to the vulnerable areas. Planting early maturing and drought resistant crops, supplementary irrigation, early waning information on weather and climate have been exercised as climate change adaptation strategies, early warning mechanisms by the government of Ethiopia. El Niño and La Niña are natural phenomena; however, it is necessary to study the occurrence and distribution of El Niño and La Niña episodes to enable early warning and identify suitable adaptation strategies and policy implications in the country.

Key words: El Niño, La Niña, statistical indices, climate change adaptation, Ethiopia

[1] Aksum University, College of Agriculture, Department of Plant Sciences, E-mail: aabay2003@gmail.com
[2] Aksum University, College of Agriculture, Department of Plant Sciences, E-mail: teklaytesfay2007@gmail.com

1. General Introduction

Climate is the primary determinant of agricultural productivity [1]. Climate change refers to *a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer [21]*. Climate change is expected to influence crop and livestock production, hydrologic balances, input supplies and other components of agricultural systems [1].

Climate change can occur through natural physical and chemical processes and through human activities. Global atmospheric concentrations of CO2, CH4, and N2O have increased since 1750. Changes in the atmospheric concentrations of GHGs and aerosols, land cover and solar radiation alter the energy balance of the climate system; leading to climate change on the Earth.

Global total annual anthropogenic GHG emissions have grown by 70% between 1970 and 2004 [21]. Application of suitable cliamte change adaptation and mitigation practices have played a great role in reducing the impacts of climate change on natural resources, crop production and food security. Plant breeding, biotechnology, and conservation agriculture are important strategies [33] in climate change adaptation.

Climate change adaptation and mitigation strategies

Application of sustainable adaptation and mitigation options to reduce or control climate change impacts are of paramount importance. According to the IPCC [21] report, climate change adaptation mitigation options have been identified and among the most relevant adaptation and mitigation options relevant to the agricultural sector.

However, climate change impacts assessment, uncertatinties in climate change predictions are of important issues. Uncertainties in climate change come from three main sources;

A. uncertainty in forcing scenarios,
B. uncertainty in modeled responses to given forcing scenarios, and
C. uncertainty due to missing or misrepresented physical processes by models [33].

The agricultural sector is the most velnurable sector to climate change, and among the potential direct effects of climate change on agricultural systems are:

1. Seasonal changes in rainfall and temperature could impact agro-climatic conditions, altering growing seasons, planting and harvesting calendars, water availability, insect pests, weeds and diseases populations, etc.

2. Evapo-transpiration, photosynthesis and biomass production is altered.
3. Land suitability is altered.

These impacts severely affect the agricultural production in developing countries. Recurrent drought impacts affect crop production, and food security, with most sever impacts in areas where erratic and inadequate rain prevails. Hence the arid and semi-arid areas of Ethiopia suffer from recurrent droughts (prolonged dryspells) causing crop loss and animal feed shortages. Rainfall variability affects crop production trends in Ethiopia [8].

El Nino has been the most important natural calamity causing crop loss, shortage of water, food and feed for animals, and human beings and livestock in Ethiopia. In Ethiopia, the first public report on El Nino was on August 5, 1997, experts from the NMA had interview on Ethiopian TV explaining the role of El Nino in drought [41]. On the contrary, La Nina phenomena also affected agricultural production, food security causing death of human beings and livestock as a result of flooding and excess rainfall which can harm crop production. So, understanding the importance of El Nino in the Ethiopian climate and livelihood of the population; this paper has been reviewed to assess comprehensive scientific literatures on the impact of El Nino and la Nina on Agriculture in Ethiopia, and to explore climate adaptation strategies to ensure food security.

2. Climate change impact in Ethiopia

Ethiopia is often cited as one of the extreme examples with regard to climate change impacts, with reference to the 1980s famine main climate hazards in Ethiopia are associated with rainfall variability, including amount, timing and intensity and its droughts and floods [10]. Drought is a recurrent feature in Ethiopia; with some 80% of the rural households have suffered a harvest failure in the last 20 years [42].

Rainfall variability in Ethiopia is caused by different factors; among these, the north movement of the Inter-Tropical Convergence Zone (ITCZ) [41]. Rainfall pattern in Ethiopia shows no marked emergent changes and future climate projections show continued warming but very mixed patterns of rainfall changes [10]. According to Gebre *et al.* [17], results from emission scenarios of GCMs indicate that there will be an increase in minimum and maximum temperature in 2030 and 2050 in Ethiopia, with no variability in total rainfall.

Crop yield obtained from rain-fed in Ethiopia are very low due to crop failures as a result of irregular rainfall pattern, and inadequate rainfall during the crop growing season. For example: report, the rainy season in northern Ethiopia is shorter than the crops growing period, indicating that most of the crops require not less than 80 days, however, the rainy season is not often exceeding 65 days [5]. The erratic rainfall pattern in such areas, where moisture is a limiting factor, the probability of receiving optimum rain for the growth and development of crops is limited; thus, yield failure is an important problem for farmers in the region. The high topography of the African coast diverts the main monsoon flow northwards and eastwards, which means that in Ethiopia, rain during the boreal summer is associated with the migration of the inter-tropical convergence zone (ITCZ) rather than the southwest monsoon winds [19].

El Niño and La Niña, and their Impacts

El Nino and La Nina result from interaction between the ocean and the atmosphere in the tropical Pacific. The increase in the temperature of the surface water bodies is part of the oceanic response to the altered atmospheric conditions, especially the changes in the trade winds over the Pacific Ocean [32].

Every several years, Sea Surface Temperature (SST) rises anomalously near the end of each calendar year, warming ocean surface temperatures along the coasts of Ecuador and northern Peru; and local residents referred to this annual warming as 'El Niño'. The meaning of the word "Niño" in Spanish is 'The Child' due to its appearance around the Christmas season [38], which indicates the end of the fishing season and the arrival of the time for Peruvian fisher-men to repair their nets and maintain their boats; this phenomena brings [28]. There are commonly used terms for El Niño; "Pacific warm episode" and El Niño/Southern Oscillation (ENSO) episode.

Depending on the intensity and duration of El Niño, the impacts may vary from place to place and time to time. Generally, the major consequences of El Niño are;

- Abnormally warm sea surface temperature from the date line (180^0 longitude) east to the South American coast,
- Changes in the distribution of tropical rainfall from the eastern Indian ocean east to the tropical Atlantic ocean,
- Changes in sea level pressure throughout the global tropics (low-index phase of the Southern oscillation), and

- Large-scale atmospheric circulation changes in the Tropics and portions of the extra-tropics in both hemispheres [28].

Generally, El Nino is a recurrent weather phenomenon occurring every two to seven years lasting 12 to 18 months; defined by high oceanic Nino Index (ONI) based on the Sea Surface Temperature (SST) departures from the average in central equatorial pacific region [16]. It plays a major role in causing Tropical droughts [9].

3.1 La Niña

Unlike El Niño episode, La Niña is characterized by anomalously cool water in the central and east central equatorial Pacific resulting in changes in the intensity and distribution of rainfall in the Tropics and changes in the patterns of sea level pressure (high index) phase of the Southern Oscillation and atmospheric circulation [28]. La Niña phenomenon is commonly named as 'Pacific cold episode'.

3.2 Effect of El Niño in Ethiopian

El Niño affects biodiversity and natural resources, ecosystem, agriculture, water availability, soil fertility, public health, energy supply and marketing. In Ethiopia, the 2014/15 was the hottest years on record [30], causing a huge yield failure and food insecurity. The 2015 El Nino caused even a complete yield failure of major field crops (Sorghum, sesame) in the Northern Ethiopia.

In 2015, El Niño triggered drought in Eastern African countries such as Ethiopia, Somaliland and Punt-land, Sudan, Eritrea, Djibouti and eastern Chad; causing sever water shortage, increasing water borne diseases, poor sanitation and hygiene, and migration and death of livestock. Ethiopia is affected by recurrent droughts as a result of climate change, which El Nino is among these natural calamities. It caused 50 to 90% crop failures, particularly in the eastern parts of the Ethiopia, loss of thousands of livestock, and malnutrition [30].

Table 1: El Niño occurrence in Ethiopia from 1987 to 2009

Year	Season
1987	First crop season
1991	First and second crop season
1997	First crop season (moderate)
2002	First and second crop season
2003	First crop season
2004	First crop season
2006	First crop season
2009	First crop season (severely affected)

Source: Rojas [35]

Ethiopia has been hit with drought for several decades. The Northern parts of Ethiopia including Tigray and Wollo, Afar, Harar and Somali are affected by drought which causes losses of food for human being and feed for animals, water shortage, and death of livestock. This causes instability and food insecurity. NMA has been forecasting the El Nino occurrence and early warning in different areas in Ethiopia. The major El Nino occurrence and its impacts at different times in Ethiopia are presented in Table 2.

Table 2: Chronology of El Nino and Climate-related risks in Ethiopia

El Nino	Year/s	Types	Affected	Killed	Regions
1953	1953	Drought	NA	NA	Tigray, Wollo
1957-58	1957-58	Drought	NA	NA	Tigray, Wollo
	1965	Drought	150,000	2000	
	1968	Flood	10,000	1	
	1969	Drought	170,000	unknown	
1972-73	1973-74	Drought	300,000	100,000	Tigray, Wollo
	1976	Flood	50,000	unknown	
	1978-79	Drought	250,000	157	
1982-83	1983-85	Drought	7,750,000	300,000	Ethiopia

1986-87	1987-88	Drought	330,000	367	Ethiopia
	1989-90	Drought	2,300,000	unknown	Northern Ethiopia, Harer
	1990	Flood	350,000		Northern Ethiopia, Harer
1991-92	1991-92	Drought	6,160,000		
1993	193-94	Drought	6,700,000		Tigray, Wollo
1996	1996	Flood			East Ethiopia
1997	1997-98	Drought Flood			North and East Ethiopia

Source: Welde-Georgis et al. [41]

3.2.1 Consequences and impacts of El Nino in Ethiopia

El Nino exacerbated by climate change causes its negatives impacts in Ethiopia at different times. There are social, agricultural, health impacts and etc. impacts under the El Nino phenomena. Among these very important impacts;

- agricultural production system is tremendously affected by El Nino: for example the recent El Nino episode in 2015 caused crop failure, feed for animals and lack of water in different areas around the country; Tigray, Afar, Somali and Oromia regions.
- Social impacts: as a result of lack of water for human beings and livestock, many thousands of people suffer.
- Health: lack of food causing malnutrition especially children are suffered and died.
- Food insecurity: with more impacts in the pastoralists and semi-pastoralists in Somali and Afar, food insecurity has been challenging for the government of Ethiopia.
- Food aids from the central government, and feed for animals were transported from the western parts of Tigay to the vulnerable and impacted areas in the southern parts of Tigray in 2015.

3. Determining and detecting El Nino events

1. **Oceanic Niño Index (ONI)**:

The Oceanic Nion Index has become the *defacto* standard as the National Oceanic and Atmospheric Administration (NOAA) uses to identify El Nino (warm) and La Nina (cool) events in the Tropical Pacific. It is the three month mean SST anomaly for the El Nino 3.4 region (i.e. 5^0N-5^0S, 120^0- 170^0 W). The events are defined as 5 consecutive overlapping 3 month periods at or above the +0.5^0C anomaly for warm (El Nino), events and at or below the -0.5^0C anomaly for cold (La Nina events) [35].

2. **Agricultural Stress Index System (ASIS)**:

Global Information and Early Warning System (GIEWS) and the Climate, Energy and Tenure Division (NRC) of FAO developed ASIS to detect agricultural areas with high likelihood of water stress or drought on a global scale. ASIS integrates the Vegetation Health Index (VHI) in two dimensions that are critical to assess a drought event in agriculture; temporal and spatial [35]. ASIS assesses the temporal intensity and duration of dry periods and calculates the percentage of arable land affected by drought as pixels with a VHI value below 35%.

3. **Southern Oscillation Index (SOI):**

The SOI gives an indication of the development and intensity of El Nino or La Nina events in the Pacific Ocean. The SOI is calculated using the pressure differences between Tahiti and Darwin. Sustained negative values of the SOI below -8 often indicate El Nino episodes. These negative values are usually accompanied by sustained warming of the central and eastern tropical Pacific Ocean and a decrease in the strength of the Pacific trade winds. Whereas, sustained positive values of the SOI above +8 are typical of a La Nina episode, which are associated with stronger Pacific trade winds and warmer Sea temperatures to the north of Australia. In this regard, water in the central and eastern tropical Pacific Ocean become cooler during this time [35].

The agricultural stress index (ASIS), based on the vegetation health index (VHI) assesses the temporal intensity and duration of dry periods, and it calculates the percentage of arable land affected by drought as pixels with a VHI value below 35%. So, based on the index of intensity of El Niño effects, the El Niño intensity during the El Niño episodes at different years are classified as weak, moderate and strong [15].

Table 3: Intensity of El Niño occurred from 1952 to 2014/15

Weak	Moderate	Strong
1952-53	1951-52	1957-58
1953-54	1963-64	1965-66
1958-59	1968-69	1972-73
1969-70	1986-87	1982-83
1976-77	1991-92	1987-88
1977-78	1994-95	1997-98
2004-05	2002-03	2015[a]
2006-07	2009-10	
2014-15		

Source: FAO [15]

[a]El Niño 2015 was obtained from Agricultural knowledge, learning documentation and policy [2]

The FAO's ASIS results indicate that in the 1985 to 2003 timeframe, in four out of the nice El Niño years (1987, 1991, 2002 and 2009), unfavorable crop growing conditions prevailed, while in the remaining five years (1986, 1994, 1997, 2004 and 2006), crop growing conditions were favorable. The seasonal rainfall seasons in Ethiopia are (1) February/March to May, (2) June/July to September and (3) October to November. The impact of EL Nino proceeds to affect in Ethiopia, with Oromia, Somalia and SNNP severely affected.

4. Impact of El Nino and La Nina on Agricultural Production and Food Security in Ethiopia

In Ethiopia, the impact of El Nino was of multidimensional. It affected crop production leading to crop yield failure, lack of water, natural resource degradation, food insecurity, market inflation, death of animals from lack of feed and malnutrition.

1. **Crop production and livestock in Ethiopia**:

Crop production in Ethiopia is dependent on rainfall. In the semi-arid areas of Ethiopia, recurrent droughts affect crop production, crop yield failure and loss of animal feed are challenging. The 2015/16 El Nino episode in Ethiopia caused huge crop yield failure resulting in food insecurity, and lack of feed for animals.

Figure 1: Effect of El Nino on Sesame and sorghum crops in 2015 in Humera, Ethiopia (Photo by Berhane [7]

In the Upper Awash region, major cereal crop productivity has decreased by 10.1% and 9.1% due to El Niño and La Nina, and to about 16% in regionalized area three (A3) [3]. Similarly, El Niño has reduced sesame productivity by 30% in the 2015 El Niño episode in Ethiopia [7].

The extreme dry season in 2015/16 cropping season caused lack of fodder for animals. Farmers were forced to sell animals due to lack of feed and water, with severe impacts in the pastoral and agro-pastoral areas in Somali, Afar and Oromia regions. In Tigray, Afar, oromia and Somalia regions, it has been tried to rescue the life of many animals by transporting feed from other areas, for example: in Tigray region, feed for animals was transported from the western part to the vulnerable areas around Raya areas.

2. Food security:

Food security can be explained in many ways; however, it can be defined as to show its components. According to the FAO [12] food security is defined as 'a situation that exists when people have secure access to sufficient amounts of safe and nutritious food for normal growth, development and an active and healthy life'. However, the major challenge of the 21st century is to achieve food security under marked shifts in climatic risks and with environmentally sound farming practices [36].

Agriculture, rural livelihoods, sustainable management of natural resources and food security are inextricably linked within the development and climate challenges of the twenty-first century [13]. Food security is highly vulnerable to climate related risks in Ethiopia. due to the high dependence on rainfall for most agricultural activities in Ethiopia, the main causes of vulnerability to climate change conditions in Ethiopia include very high dependence on rain-fed agriculture, impact on water resources, low health service coverage, high population growth rate, low economic development level, low adaptive capacity, inadequate road infrastructure in drought prone areas, weak institutions, lack of awareness, etc. Therefore, the negative impacts of climate change in Ethiopia will be severe, especially, with the poor, agro-pastoralists, and in areas where, inadequate infrastructure is available; for example, irrigation, transport, market, etc.

Food insecurity will continue to be a serious issue in coming decades, despite significant projected hunger by the end of the century from the current 850 million to about 200-300 million [27]. This can be due to several factors, many developing countries will experience serious poverty and food insecurity; due to localized high population growth rates, poor socio-economic capacity and continued natural resource degradation, with 40-50% of all under nourished from Sub-Saharan Africa [13].

Ethiopia is one of the largest recipient of humanitarian assistance in the Sub-Saharan countries. Ethiopia received 5.6 billion $US in 2004-2013 [18]. Following the 2015 El Nino in Ethiopia, urgent food assistance rose from 2.9 million in January 2015 to 9.7 million in August 2016 [6].

Table 4: Estimated humanitarian needs in 2015/16 and 2011 drought responses

	2016 revised HRD	2011 revised HRD
people in need of food assistant	9.7 million	4.5 million
Child<5 years and PLW in need of NAM treatment	2.36 million	708,921
Children<5 in need of SAM treatment	420,000*	327,750
Screening for malnutrition caseload	13 million	3.35 million

HRD: humanitarian requirements document

*2016 figures might have been more accurate if more experts had been involved in the calculation of needs

Source: [6]

Food security is highly sensitive to climate risks in Ethiopia. According to the NMA [27], the major adverse impacts of climate variability in Ethiopia include;

1. Food insecurity arising from occurrence of droughts and floods;
2. Outbreak of diseases such as malaria, dengue fever, water borne diseases (such as cholera, dysentery) associated with floods and respiratory diseases associated with droughts;
3. Land degradation due to heavy rainfall and;
4. Damage to communication, road and other infrastructures by floods;

5. El Nino and La Nina Adaptation Strategies in Ethiopia

The government of Ethiopia is has been taking the initiative in providing adaptation and mitigation strategies and settle the livelihood of vulnerable communities in different areas around the country. Food aid, feed for animals, water, health and hygienic tools have been distributed and agriculture related interventions were distributed to Afar, Somalia, Oromiya, Amhara, Tigray and other impacted areas by the government, and humanitarian organizations. El Nino phenomenon is a natural climate calamity, disrupting the tropical climate and triggering severe drought and flood. It occurs two to seven years.

Drought Insurance in Ethiopia:

The agricultural sector in Ethiopia is highly vulnerable to climate variability. Crop production is predominantly based on rain-fed conditions. Drought is among the major climate related natural hazards affecting crop production and livelihood of millions of people in Ethiopia. More than 85% of the population in Ethiopia depends on agriculture. However, climate variability affects crop production, animal husbandry, natural resources and food security. El Nino is one of the most negatively affecting natural calamities in Ethiopia. Torrential rains causing flooding destroys crop areas, residence areas and infrastructures. On the other hand, recurrent drought causes loss of crop yield, animal feed and water for animals and human beings.

Therefore, as adaptation strategies for these circumstances, the government of Ethiopia provides a new insurance policy 'weather insurance' as an important risk minimization strategy for farmers reduce the impact of crop loss.

6. Conclusions and recommendations

Climate change is the main determinant of agricultural productivity; influencing crop and livestock production, hydrologic balances, input supplies, natural resources and other components of agricultural systems; with sever impacts in developing countries as a result of low adaptive capacity. It affects crop growth and yield, water availability and productivity, soil water balance either directly or indirectly.

Climate change predictions indicate a warmer world within the next 50 years. maximum and minimum temperature ranges projected to increase causing substantial yield decrease in low tropical and dry areas, crop productivity is projected to decrease with increase in temperature 1 to 2^{o}C [21]. Whereas, projected rainfall patters will have no distinct variability patterns. By 2080, arid and semi-arid lands in Africa will increase 5 to 8%.

Agriculture, rural livelihoods, sustainable natural resources managements and food security are inextricably linked, with in the development and climate challenges of the 21st century. El Niño has been negatively affecting crop production, livestock and food security in Ethiopia since 1953. It causes a reduction in crop productivity from complete yield failure to up 30%. It causes migration and death of animals. The Eastern and Northern parts of Ethiopia are among the most frequently and severely affected areas in Ethiopia.

Indices:

El Niño and La Niña occur at different occasions, with varying strength and impacts on human beings, natural resources, requiring environmental and political attentions around the globe. It has been tried to quantify El Niño and La Niña using several statistical indices. To highlight the different indices; Oceanic Nino Index (ONI), Agricultural Stress Index System (ASIS) and Southern Oscillation Index (SOI) are presented in this review. The ONI varies at or above $+0.5^{0}$C for warm events (El Niño episode), and at or below -0.5^{0}C anomaly at 5 consecutive 3 month periods. El Niño and La Niña episodes can be quantified when the SOI is -8 or below, and +8 or above, indicates El Niño and La Niña episodes respectively.

Research works on El Niño and La Niña episodes over long-period of time are not available as they are very a year to year phenomena in Ethiopia. Trend analysis on extreme temperature and rainfall indices have not been investigates, especially, in a way that can provide evidence with relationship on the occurrence and socio-economic, political and environmental impacts. Therefore, the following recommendations are very important to device suitable adaptation strategies.

1. Weather prediction and forecasting is not accessible to farmers, investors, pastoralists and agro-pastoralists, and agricultural experts across the country. So, the Government has to take measure commitment on producing well skilled manpower and technology to resolve the gap.
2. Universities and higher education institutions do not have commitment to investigate climate change and variability, particularly, El Niño and La Niña events, which cause a considerable loss in Ethiopia. Therefore, trend analysis either by governmental and non-governmental Universities should give due attention on the impacts and consequences and devote their expertise in exploring and investigating El Niño and La Niña episodes over wider scopes, by incorporating in their curriculums.

3. Farmers, investors, agricultural experts and other stakeholders in the agricultural sector do not have awareness on when the extreme climate episodes occur, to provide preparedness and early warning. In this regard, awareness creation on El Niño and La Niña episodes is very important, which the Government should work on.
4. There is lack information on weather forecasting, besides not inclusive. Except, for major cities in Ethiopia; the National meteorological agency (NMA) of Ethiopia does not address the remaining vast area across the wider agro-ecology. The agro-ecology in Ethiopia is highly diversified; weather and climate conditions are variable. So, timely and accurate weather prediction and forecasting for a specific location is highly required. Thus, it is recommended that the NMA should expand its access based on the wider agro-ecological zones and hotspot areas.

Conflict of Interest

The author declares there is no conflict of interest in publishing this manuscript.

Bibliography

[1] Adams, R. M., Hurd, B. H., Lenhart, S., & Leary, n. (1998). Effects of Global Climate Change on Agriculture: an Interpretative Review. *Climate Research , 11*, 19-30.

[2] AKLDP. (2015). *EL Nino IN Ethiopia: Uncertainties, Impacts and Decision Making.* Technical Brief.

[3] Alemu, A., Korecha, D., & Mohamod, M. (2017). Impacts of Various ENSO Phases on Cereal Crop Productivity in the Upper Awash Basin Central High Land of Ethiopia. In S. WD., T. T., N. D., F. K., F. B., M. K., et al. (Ed.), *Proceedings of the International Conference on Impact of El Nino on Biodiversity, Agriculture, and Food Security* (pp. 3-17). Haramaya University (Ethiopia: Haramaya University and MoEFCC.

[4] Allen, G., Luis, S. P., Dirk, R., & Martin, S. (1998). *FAO Irrigation and Drainage Paper NO. 56: Crop Evapotranspiration (Guidelines for computing crop water requirements).* Rome (Itlay): FAO.

[5] Araya, A., & Stroosnijder, L. (2010). Effects of Tied Ridges and Mulching on Barley (Hordeum vulgare) Rainwater use Efficiency and Production in Northern Ethiopia. *Agricultural Water Management , 97*, 841-847.

[6] Babu, G., Rutishauser-Perera, A., & Prudhon, C. (2017). *Assessing the Differences in the Scale of Nutrition Response Effects to El Niño in Ethiopia.* ENN UK .

[7] Berhane, A. (2016). *Effect of Supplementary Irrigation on Sesame crop Growth and Productivity.* Unpublished Report, Addis Ababa (Ethiopia).

[8] Bewket, W. (2009). Rainfall Variabiity and Crop Production in Ethiopia: Case Study in the Amhara Region. *Proceedings of the 16th International Conference of Ethiopian Studies,* (pp. 823-836). Trondheim.

[9] Coelho, C. A., & Goddard, L. (2009). El Nino-Induced Tropical Droughts in Climate Change Projections. *Journal of Climate , 22*, 6456-6476.

[10] Conway, D., & Schipper, E. l. (2011). Adaptation to Climate Change in Africa: Challenges and opportunities Identified from Ethiopia. *Global Environmental Change , 21*, 227-237.

[11] Falkenmark, M., Rockström, J., & Karlberg, L. (2009). Present and Future Water Requirements for Feeding Humanity. *Food Science , 1*, 59-69.

[12] FAO. (2008). *Climate Change Adaptation and Mitigation in the Food and Agriculture Sector.* Rome (Italy).

[13] FAO. (2012). *Climate Change Adaptation and Mitigation; Challenges and opportunities in the Food Sector.* Rome (Italy): FAO.

[14] FAO. (2011). *Climate Change, Water and Food Security: FAO Water Reports (36).* Rome(Italy): FAO.

[15] FAO. (2014). *Ethiopia: El Niño-Southern Oscillation (ENSO) and the Main Kiremt Rainy Season: An Assessment Using FAO's Agricultural Stress Index System (ASIS).*

[16] FAO-GIEWS. (2015). *El Nino Southern Oscillation (ENSO): Possible Impact on Agricultural Production During the Second Half of 2015.* GUIWS update, GIEWS update.

[17] Gebre, H., Kindie, T., & Girma, M. (2015). Analysis of Climate Change in Northern Ethiopia: Implications for Agricultural Production. *Theorotical and Apllied Climatology , 121*, 733-747.

[18] GHA. (2015). *Global Humanitarian Assistance Report.*

[19] Gissila, T., Black, E., Grimes, D., & Slingo, J. (2004). Seasonal Forecasting of the Ethiopian Summer Rains. *International Journal of Climatology , 5*, 1345-1358.

[20] ICARDA, & CCAFS. (2012). *Strategies for Combating Climate Change in Drylands Agriculture.* Doha (Qatar).

[21] IPCC. (2007). *Climate Change 2007: Fourth Synthesis Report.*

[22] IPCC. (2013). *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate ChangePCC).* (S. T.F., D. Qin, G.-K. Plattner, M. Tignor, S. Allen, J. Boschung, et al., Eds.) Cambridge, United Kingdom, New York, USA: Cambridge University Press.

[23] IPCC. (2000). *Emission Scenarios: Summary for Policy Makers; A Special Report of IPCC Working Group III.* IPCC.

[24] Jones, J. W., Hoogenboom, G., porter, C. H., Boote, K. J., Batchelor, W., hunt, L., et al. (2003). The DSSAT Cropping System model. *European Journal of Agronomy , 18*, 235-265.

[25] Kang, Y., Khan, S., & Ma, X. (2009). Climate Change Impacts on Crop Yield, Crop Water Productivity and Food Security: A Review. *Progress in Natural Science , 19*, 1665-1674.

[26] Ngigi, S. N. (2009). *Climate Change Adaptation Strategies: Water Resources Management Options for Smallholder Farming Systems in Sub-Saharan African.* The MDG Centre for East and Southern Africa of the Earth Institute at Columbia University, New York with financial support from the Rockefeller Foundation.

[27] NMA. (2007). *Climate Change National Adaptation Program of Action (NAPA) of Ethiopia.* Addis Ababa: NMA.

[28] NOAA. (2006). *What are El Niño, La Niña, and ENSO?*

[29] Oweis, T., & Hachum, A. (2012). *Supplemental Irrigation a Highly Efficient Water Use Practices* (2 ed.). Aleppo, Syria: ICARDA.

[30] OXFAM. (2015). *El Nino in Ethiopia: Program Observations on the Impact of the Ethiopia Droughts and Recommendations for Action.*

[31] OXFAM. (2015). *Entering Uncharted Waters: El Nino and the Threat to Food Security.*

[32] Philander, S. G. (1999). El Nino and La Nina Predictable Climate Fluctuations. *Reports in Progress in Physics , 62*, 123-142.

[33] Reynolds, M. P. (Ed.). (2010). *Climate Change and Crop production* . CABI Climate Change Series.

[34] Rockström, J. (2000). Water Resources Managment in Smallholder Farms in Eastern and Southern Africa: An Overview. *Physics.Chemistry. Earth , 25* (3), 275-283.

[35] Rojas, O., Li, Y., & Cumani, R. (2014). *Understanding the Drought Impact of El Nino on the Global Agricultural Areas: An Assessment Using FAO'S Agricultural Stress Index.* Rome (Italy): FAO.

[36] Rötter, R. P., Sehomi, F. L., Höhn, J. G., Niemi, J. K., & Berg, M. v. (2016). *On the Use of Agricultural System Models for Exploring Technological Innovations Across Scales in Africa: A Critical Review.* Bonn: Zentrum für Entwicklungsforschung (ZEF).

[37] SEI. (2009). *Opportunities to Increase Water in Agriculture with Special Reference to Africa and South Asia.* New York: Stockholm Environment Institute (SEI).

[38] Trenberth, K. E. (1997). The Definition of El Niño. *Bulletin of the American Meteorological Society , 78* (12), 2771-2777.

[39] Turral, H., Burke, J., & Faures, J.-a. (2011). *Climate Change, Water and Food Security.* Rome (Italy): FAO.

[40] Welde-Georgis, T. (1997). Grought Crisis Management, the Case of Ethiopia: In Using Science Against Famine: Food Security, Famine, Early Warning and El Nino. *Internet Journal for Afrcan Studies* .

[41] Welde-Georgis, T., Aweke, D., & Hagos, Y. (2000). *The Case of Ehiopia: Reducing the Impacts of Environmental Emergencies Through Early Warning and Preparedness: Case of the 1997-98 El Nino.*

[42] World-Bank. (2006). *Weather Risk Management: An Ethiopian Pilot.*

[43] Yosef, B. A., & Asmamaw, K. (2015). Rainwater Harvesting: an Option for Dryland Land Agriculture in Arid and Semi-arid Ethiopia. *International Journal Water Resources and Engineering , 7* (2), 17-28.