World Journal of Agricultural Sciences 17 (2): 81-89, 2021
ISSN 1817-3047

DOI: 10.5829/idosi.wjas.2021.81.89

Impact of Climate Change on East African Coffee Production and Its Mitigation Strategies

Dadi Tolessa Lemma and Habtamu Gudisa Megersa

Ethiopia Institute of Agricultural Research,
Wondo Genet Agri. Research Center, P.O. Box: 198, Shashemene, Ethiopia

Abstract: Coffee is the most traded commodity in the world. East Africa is one of the coffee producers as well as an area of origin and diversity of coffee which can be affected by climate change. According to ICCP report, global temperature has been rising by nearly 1°C and is expected to be rise to 2.5°C at optimum and 4.5°C at worst scenarios. This change is very frustrating to coffee production since it is very sensitive and has narrow temperature and precipitation range. Many have predicted that coffee production and productivity will be reduced in coffee producing areas of eastern Africa and even the genetic diversity and loss is in question. Most of the scholars have predicted current coffee producing areas will not suitable for coffee production and there will be suitability shift to high land areas to meet market demand, based on the niche model simulations, for the main coffee producing countries of Africa for both Arabica and Robusta coffee. Impacts are highly negative for Arabica coffee, with Arabica suitable areas of Mozambique, Uganda and Tanzania almost disappearing >50%, areas of Burundi and Rwanda will be reduced significantly by 20-50 % and the least significant but still noticeable negative effects on Kenya and Ethiopia <15% reduction. For Robusta coffee, models indicated that three countries might experience substantially negative impacts: Mozambique, Uganda and Tanzania, whereas the rest of countries Ethiopia, Kenya, Rwanda and Burundi are more likely to experience gains in Robusta-suitable areas. To reduce the impact of climate change on coffee productions, east African countries have to search some mitigation strategies to adapt to the climate change situations. Since suitability shift is suggested for coffee production in the future high land that is suitable for coffee production should be selected without affecting food crop production and areas covered by forest.

Key words: Arabica Coffee · Precipitation · Projection · Suitability · Temperature

INTRODUCTION

Coffee is the second major traded commodity next to petroleum oil and balance trade between developed and developing countries [1]. Among *Coffea* genus, *Coffea arabica* L. (Arabica coffee) and *Coffea canephora* (Robusta coffee) species economically dominate the world coffee trade, being responsible for about 99% of world bean production [2]. Arabica coffee accounts for about 70% of coffee consumed and Robusta coffee for the rest [3]. Coffee is an important exchange commodity contributing in various degrees to national income of the producing countries [4]. The chief producers of coffee include Brazil, Vietnam, Colombia, Indonesia and Ethiopia. The livelihoods of more than 125 million people rely on a global trade worth over US$19 billion [5].

Arabica is dominant in East Africa. Ethiopia, Kenya, Rwanda, Malawi and Zambia primarily grow Arabica. Uganda predominantly grows Robusta, while Tanzania grows both types, mostly Arabica. Optimum growing temperature for Arabica is 18–23°C while for Robusta is 22–26°C [5]. Arabica grows well at an altitude between 1000 to 2000 m a s l with an annual rainfall of 1500mm to 2000 mm while Robusta varieties require 2000 mm a.s.l with an annual rainfall which growth best above sea level to 800m a.s.l [6]. Hence, Arabica is cultivated in high altitudes while Robusta is cultivated in lowlands.

Currently, our globe is in challenged with climate change which is causing an immediate and unprecedented threat to agriculture. A 10–20% decline in overall global crop yields is predicted by 2050. This is of particular importance for crops such as coffee, which serves as the

Corresponding Author: Dadi Tolessa Lemma, Ethiopia Institute of Agricultural Research, Wondo Genet Agri. Research Center, P.O. Box, 198, Shashemene, Ethiopia.

economic foundation for many countries in the tropics and on which millions of people depend for their subsistence. Climate change and variability are already having a significant impact on the agriculture sector which is an important activity in the developing world; as the sector is dominated by rain-fed crop production and household's food security is particularly vulnerable to climate variability and change [7].

There is much evidence that substantiates global warming, with increases in mean atmospheric and oceanic temperatures. The agricultural sector will face serious challenges in the coming decades due to the sensitivity of crops to water shortages and heat stress [8]. Rising temperatures have already reduced crop quality and increased the pressure of pests and diseases, reducing agricultural production worldwide. Climate change brings increased temperature, which reduces growth, flowering and fruiting. The occurrence of sporadic and low-intensity rains over the flowering period and particularly toward the later-phases of flower bud development, is thought to be one of the major factors responsible for unsynchronized fruit ripening of coffee [2].

Coffee productivity will be reduced according to some prediction as a result of climate change [9, 10] as result coffee could migrate to higher latitudes [9] or altitudes [10] which would not benefit current producers and the migration could threaten ecosystems [11]. Many researches has been conducted to study climate changes and its impact on coffee production and shows that climate change has appeared in recent years and immediately change the common perception of many people in few years, makes looking forward the serious topics of all stakeholders [12]. Jaramillo *et al*. [13] stated that even the smallest increases in temperature could cause extensive damage to coffee production. They estimate that if climate change continues on its current trend, the suitable land for growing coffee could face a reduction by up to 95 percent. Most coffee is grown in the tropics, which face severe threats of extreme climate change [13]. Between 80 and 90% of the world's 25 million coffee farmers are smallholders, they are among the people most exposed to climate change. As the world warms, market and climate volatility will combine to cause problems for producers and consumers. The evidence is now clear that climate change is already beginning to impact on coffee production, along with other key world crops [14].

Many studies have assessed the impact of climate change on coffee using different methods: use of common denominators of climate suitability to map risk areas [9]; or correlation between temporal [15] and spatial variability of coffee production [10, 16]. Simonett *et al*. [17], with Robusta in Uganda, used mean annual temperature to conclude that only high altitudes will remain suitable. Zullo *et al*. [9] included water deficit and frost risk, in addition, to mean annual temperature to project a southward migration of Arabica production in Brazil. Gay-Garcia *et al*. [15], used the correlation between yield and temperature in Mexico to suggest that economical yields would not be viable by 2020. Schroth *et al*. [10] found a similar impact on Mexican coffee with increasing temperatures. Davis *et al*. [16] concluded that areas that are climatically suitable for indigenous coffee varieties in East Africa may be substantially reduced in future scenarios.

Trends of Climate Change and Climate Variability in East Africa: The primary drivers of yields, suitability and other responses of coffee to climate are temperature and precipitation.

Temperature: Starting from 1850, the average global temperature has already risen by nearly 1°C. By 2100, the world is projected to warm by a further 2.6°C to 4.8°C in a likely scenario [14]. Global temperatures have increased by an average of 0.74°C (+0.56°C to 0.92°C) in the last 100 years (1906–2005) and this increase appears to have accelerated since the 1970s [16]. This may sound like small changes but the consequences for global agriculture and development will be far-reaching, complex and dire.

Decadal analyses of temperatures strongly point to an increased warming trend across the African continent over the last 50-100 years [18]. Surface temperatures have increased by 0.5°C or more during the last 50-100 years over most parts of Africa, with minimum temperatures warming more rapidly than maximum temperatures [18]. Over the last 50 years, there has been an increase in seasonal mean temperature in many areas of Ethiopia, Kenya, South Sudan and Uganda [18, 19]. The mean annual temperature has increased by 1.3°C between 1960 and 2006, at an average rate of 0.28°C per decade [20] and by 0.3°C per decade in the southwestern region of Ethiopia (Fig. 1) [21].

Temperature will increase by the year 2050 between 1.5°C (optimum scenario) and 4.5°C (worst scenario) with the month of May being the hottest one with temperatures exceeding 28°C; an expansion of the areas with higher temperatures is to be expected at the expense of the one where currently there are lower temperatures such as the mountainous areas [22].

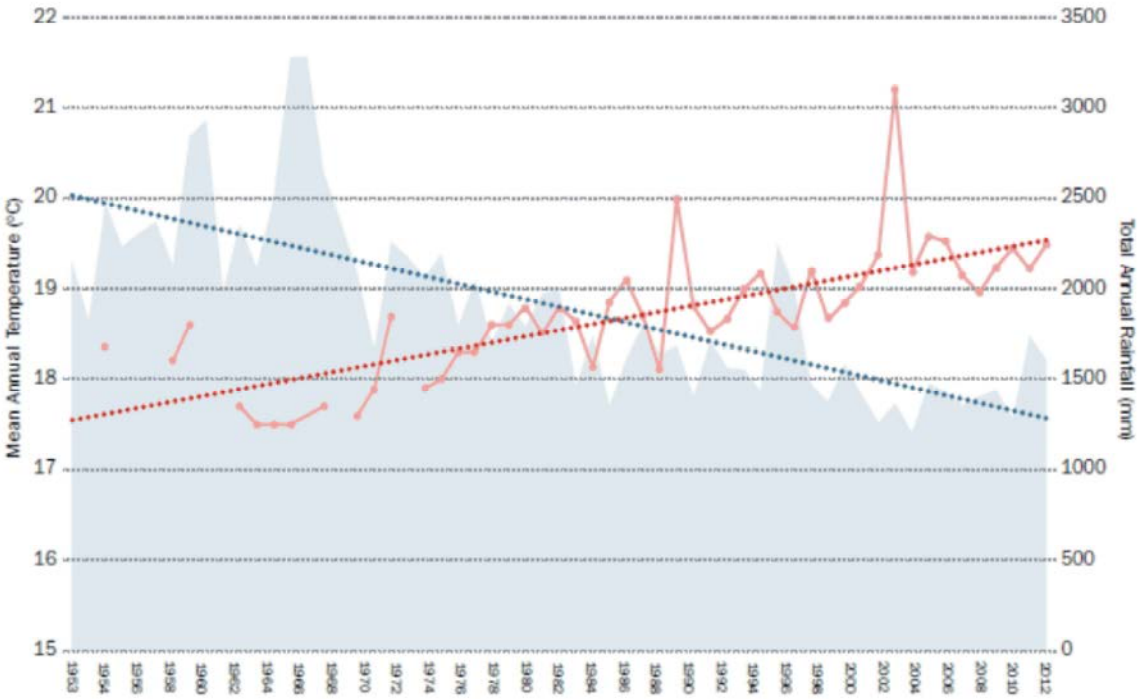

Fig. 1: Historical climate data from Gore (South West Ethiopia)
Source: Garedew, *et al*., 2017

Rainfall/Precipitation: There will be a reduction in precipitation in all three scenarios (optimum, moderate, worst) point to an average reduction in precipitations by the year 2050 for the trimester July, September with the month of August presenting the most severe reduction [22]. Precipitation in eastern Africa shows a high degree of variability with respect to location and timing (seasonality) and is highly influenced by the physical characteristics of the land surface [18]. Despite these constraints and difficulties, it has been reported that over the last three decades rainfall has decreased by around 15% over eastern Africa, in the main growing season (March and May/June) [19]. The suggested link to the decrease in rainfall is a rapid warming of the Indian Ocean, which causes an increase in convection and precipitation over the tropical Indian Ocean, contributing to the decrease in rainfall over the continental land surface. Other studies also show a decline in the March-to-May seasonal rainfall over eastern Africa [18]. In Ethiopia there was an overall reduction of rainfall of around 10% across Ethiopia (1948-2006) has also been reported [21].

It is showing an increase in average (mean) air temperature and decrease in total annual rainfall, since 1953. Solid red line and red dots show recorded annual mean temperatures (gaps in the line represent missing temperature records); blue shading/peaks show recorded total annual rainfall. Dashed red line represents the temperature trend (increasing); dashed blue line represents the annual rainfall trend (decreasing).

Inter-annual precipitation variability over East Africa arises from a complex interaction between sea surface temperature anomalies (SSTAs), large-scale atmospheric patterns, tropical cyclones and subtropical anticyclones and free atmosphere variations [23]. Relative to the long rains, the short rains tend to have stronger inter-annual variability, greater spatial coherence across a large area and more significant associations with El Nino Southern Oscillation (ENSO); warm El Nino events are associated with increased rain with negative anomalies occurring during La Nina events [23]. The link to ENSO can be further connected to outbreaks of moist South Atlantic westerly flows, which are linked to anomalous precipitation over the region and tend to increase/decrease during El Nino/La Nina episodes respectively [24]. This applies to all of the continental focus countries with the exception of Sudan [25].

Climate Change Projection and Suitability Change for Coffee Production: Climate change projections suggest that many currently cultivated areas will become less suitable for agriculture, at least for currently planted crops. There is a particular concern for coffee [26], the production of which is highly sensitive to local climate [8]. While IPCC projections encompass a global temperature rise of 2-4°C by 2081 and, more controversially, increased frequency and intensity of precipitation extremes [27], regional warming and increasingly erratic rainfall have already increased the frequency of poor harvests [28] and this has affected coffee prices regionally and even globally.

Temperature: The Representative Concentration Pathways (RCP) is the latest generation of modeled scenarios that provide input to climate models [29]. Warming projections under low emissions RCP (RCP 2.6) indicate that Africa will see a change of around 1°C (and less than 2°C) by the end of this century, relative to the late 20th century mean annual temperature baseline [18]. Under high emissions RCP (RCP 8.5) an increase of more than 2°C could occur by the mid-century across much of Africa and exceed 4°C by the end of the century [18]. It is likely that land temperatures over Africa will rise faster than the global land average, particularly in the more arid regions and that the rate of increase in minimum temperatures will exceed that of maximum temperatures [18]. In case of Ethiopia mean annual temperature is projected to increase by 1.1-3.1°C by the 2060s and 1.5-5.1°C by the 2090s, with the scale of the projections depending on the emission scenario [20].

Precipitation: Projected rainfall change over Africa in the mid and late century is uncertain. There is low confidence in projected increases of heavy precipitation over most of Africa, except East Africa, where there is a high confidence in a projected increase in heavy precipitation [29]. However, regional climate model studies also suggest drying over most parts of Uganda, Kenya and South Sudan in August and September by the end of the 21st century [30]. Projections from different General Circulation Models (GCMs) are broadly consistent in indicating increases in annual rainfall in Ethiopia [18], but these increases are largely due to increasing rainfall in the October-December period in southern Ethiopia [20]. Projections of change in the rainy seasons of April-June and July–September, which affect larger areas of Ethiopia, are much more uncertain but tend towards slight increases in the south-west and decreases in the northeast [20]. In the Ethiopian Highlands, a region of high and complex topography, projections from the GCMs also indicate likely increases in rainfall and extreme rainfall, by the end of the 21st century [18]. However, these future trends are not consistent with observed decreasing rainfall for many places in Ethiopia. Overall, projections based on GCMs for Ethiopia are highly variable [31] and for some regions, the various GCMs do not agree on the direction of precipitation trend.

Based on the niche model simulations, for the main coffee production countries of Africa for both Arabica (*C. arabica*) and Robusta (*C. canephora*) coffee Bunn *et al*. [32] indicated that, impacts are highly negative for Arabica coffee, with Arabica suitable areas of Mozambique, Uganda and Tanzania almost disappearing >50% areas of Burundi and Rwanda reducing significantly (20-50 % reduction) and the least significant (but still noticeable) negative effects on Kenya and Ethiopia (<15% reduction). For Robusta coffee, models indicate that three countries might experience substantially negative impacts: Mozambique, Uganda and Tanzania, whereas the rest of countries (Ethiopia, Kenya, Rwanda and Burundi) are more likely to experience gains in Robusta-suitable areas [32]. On the basis of these results, it is likely that two phenomena will be observed for coffee in East Africa: (1) an overall reduction in Arabica growing areas accompanied by migration and hence concentration towards higher altitudes; and (2) a replacement of heat-stressed Arabica areas (<1, 500m.a.s.l.) by the more heat-tolerant Robusta [32].

Least impact on Arabica is projected for East Africa region with 10% of suitability lost in the RCP 2.6 scenario and up to 30 % in the RCP 8.5 scenario. Globally, losses are projected to be 49 % of overall suitability score lost in the RCP 6.0 scenario by 2050. Both species lose large shares of total suitability mostly at low altitudes below 1000 masl while there will be fewer relative losses at higher altitudes. *Coffea canephora* suitability will be lost in the Congo basin with 60% (RCP 2.6) to 95 % (RCP 8.5) of total suitability lost in the center of origin of the species. Again, East Africa is projected to face the least impact. In the RCP 2.6 scenario, the loss of suitability will be between 16 % and up to 30 % in the RCP 8.5 scenario. The global losses are higher for Robusta (54 %) than for Arabica [32].

In East Africa, climates suitable for Arabica coffee are predicted to shift from 400-2000m a.s.l. to 800-2500m a.s.l. There would be little change in the suitability of the areas in Ethiopia, Kenya, Rwanda and Burundi that currently grow Arabica. There may be gains in areas at higher elevations (1500–2400ma.s.l.) become more suitable. Tanzania and Uganda would lose suitable area at elevations below 1400ma.s.l. [33].

Climate Change and Pests: The most devastating factor caused by climate change on coffee production is the outbreak of disease and insect pests and the aggressiveness of the existing pests. The most significant coffee pests which become series and damaging to climate change are leaf rust (*Hemileia vastatrix*) and the coffee berry borer (*Hypothenemus hampei*) [34]. Coffee leaf rust which is favored by high temperatures becomes more series disease and affects coffee in high altitude areas. Coffee leaf rust is one danger to coffee growth that has emerged as a result of climate change. Coffee leaf rust has attacked Arabica coffee throughout South America and Africa [35].

Jaramillo *et al*. [13] discussed that the coffee berry borer population growth has an exponential relationship with temperature increases. As temperatures rise, the population of coffee's main predator drastically increases. For Arabica, the coffee berry borer (*Hypothenemus hampei* (Ferrari) [Coleoptera]) poses a significant compounding threat to indigenous populations and plantations [16]. Coffee berry borer, the most important biotic constraint for commercial coffee bean yields worldwide. A study performed by Jaramillo *et al*. [13] determined that a 1 to 2-degree Celsius increase in temperature would cause the *Hypothenemus hampei* to develop faster; this would lead to more generations per fruiting season. They found that increases of over 2°C would force the *H. hampei* to migrate to higher altitudes. This explains the bugs' shift from a lower elevation where *Coffea canephora* grows to the higher altitudes of *Coffea arabica*. It was unable to complete a single generation per year in south-west Ethiopia (Jimma) before 1984, due to low temperatures, but thereafter, because of rising temperatures in the area, it was predicted that the pest would be able to complete one or two generations per year/coffee season [36]. *Hypothenemus hampei* is most severe on coffee at low altitude, seldom serious at over 1370m, rare at 1525m and non-existent at 1680m. However, recent observations on Arabica coffee in Eastern Uganda have found the borer at altitudes as high as 1864 masl, raising speculations about the effects of global temperature rise on the distribution of coffee pests and diseases in Uganda. Climate models predict that by 2050 the coffee berry borer will be particularly damaging to high-quality Arabica coffee at 1200-1800 masl in East Africa and that the number of generations of coffee berry borer per season could double to 5-10 [37].

Climate Change and Coffee Quality: A quality problem could arise, from the faster plant growth that will lead to lower coffee fruit quality. Besides, high maximum temperatures during summer months may cause an excessive fruit ripening, against fruit quality [2]. Coffee trees are resistant to high summer temperature and drought, but the increase of extreme conditions can be responsible for physiological stresses, such as the reduction of photosynthetic efficiency [22]. Other critical phases are flowering, in relation to the breaking of bud dormancy break and grain fill. Moreover, high temperature and dry conditions during the reproductive phase can be critical for the optimum coffee production and quality. The setting of adequate air temperature limits for coffee is decisive for the distribution and economic exploitation of the crop [38].

The scenarios on climate change of the International Panel on Climate Change (IPCC) predict for most parts of the Central American region an increase in mean annual temperature between 1–2°C until 2050. Consequently, the optimal climate conditions for Arabica coffee cultivation in most of the current production regions are likely to change. In addition, higher temperatures improve living conditions for pests and diseases. Increasing pest attacks lead to the loss of quality of the coffee beans or even to the destruction of yield and plants [22].

An estimated 25 million farmers produce coffee on over 11 million ha, most of whom are smallholders who depend on coffee for their livelihoods. This web of small coffee farms is important in the economies of some developing countries, for example, coffee contributes 59% of Burundi's export earnings, 33% for Ethiopia and 17% of Nicaragua's [5]. Ovalle-Rivera *et al*. [33] predicted that climate change will affect Arabica coffee production of the current growing regions since the increase in temperature reduce yield and quality of the coffee.

Mitigation Strategies: The application of different adaptation techniques in East Africa should aim to improve several critical components including soil health, water conservation, livelihood diversification and the capacity of local institutions. GHGs can be released in the course of coffee production through the application of fertilizers and pesticides, direct fuel and electricity use, de-pulping and fermentation resulting in methane and release of nutrients from the soil. Account for all of these, traditional and commercial coffee poly-cultures have a low carbon footprint, while monocultures produce 50% more GHGs [39].

Agroforestry and Shade Management as a Means of Adaptation: Increasing biodiversity in coffee plantations is a known and important strategy for building up the system's resilience [40]. Specifically, the practice of introducing shade trees into coffee plantations is considered a sound adaptation strategy to rising temperatures. Shade trees protect plants from microclimate variability [40], from the effects of lower precipitation and reduced soil water availability and reduce high solar radiation, hence buffering detrimental diurnal changes in air temperature and humidity [41]. In addition, coffee agroforestry has other positive effects on the crop like improved soil fertility, protection from insect pests [42] and economic benefits for farmers [43]. Wild *C. arabica* grows as an understory tree of forests in East Africa [44] and until the 1970s it was predominantly cultivated under shade. However, due to increased market demand and the introduction of sun-resistant varieties, coffee growers had incentives for increasing productivity on their farms. This led to a gradual elimination of shade trees on the plantations [45]. These changes in production practices are becoming problematic in many coffee production areas due to higher pest and disease pressure, largely driven by global environmental change.

Possible solutions to lower the impact of climate change on coffee are to shade the areas where coffee is produced [35]. Shade management is highly advisable when coffee is grown in less desirable areas, or in areas that will become affected by climate change. The main effects are decreasing air temperatures as much as 3°C - 4°C, decreasing wind speeds and increasing air humidity. Shading also helps avoid large reductions in night temperatures at high elevations [46]. They also added that increasing organic matter and soil water retention capacity, thereby enhancing the viability of cultivation under adverse climatic conditions is one mechanism of mitigation strategy for coffee production.

Many scholars suggested that using shade can preserve Arabica coffee from damage because of high temperature [8, 36] by blocking suns impact on the plant. They create lower temperatures better suited for Arabica coffee plants. Jaramillo *et al*. [36] say shade trees can cause a reduction in temperature by up to 4°C. The author also added that the use of shade can minimize the population of coffee berry borer by about 34 percent which helps the stability of coffee. Garedew *et al*. [47] compared the temperature change under shade and open field found that shade can decrease temperature up to 1°C which have great implication in climate change. According to Oxfam research report 2013 cited in Msuya [7] exposed adding of shade in the coffee farm can reduce the temperature in the coffee canopy by 2°C. Shade trees or shade crops like bananas have benefited both in long-term for farmers as they help to cope the system to increasing temperatures. The coping strategies have helped to maintain household welfare during periods with stress from shocks [7].

Shifting to High Elevations: Several researchers argue that coffee plants should be moved to higher elevations where temperatures are usually a few degrees cooler [8, 16, 36]. But this may not feasible since there may not be access land to use for production since may are cultivated for food crop or unsuitable for production. For example, Arabica coffee would need to move 167 meters higher in elevation for every 1°C increase. Regional studies of the impact of climate change on Arabica coffee have shown variability and the suitable area will decrease and move to higher elevations [33].

Robusta Coffee Production: Despite its lower quality, Robusta is more tolerant of climate change and heat; it does not depend as much on rainfall. Researchers are searching for ways to improve the taste of Robusta, but have been unsuccessful so far.

Genetic Breeding: The main objectives of this concept are the development of higher yields, better quality and strength and longevity. However, it is equally important that genetic improvement based on selective breeding contributes to the long-term sustainability of coffee cultivation in lands potentially affected by climate change. Research on varieties that are less water demanding is equally important. Some research has focused on developing varieties that could cope with higher temperatures and remain highly productive at the same time [46].

Greenhouse Gas Reduction: Some study suggested that to enhance coffee production and to take control over coffee price reduction of greenhouse gas emission should be done to minimize climate change. The possible way to reduce greenhouse gas emission is by minimizing deforestation and proper crop management [8].

Irrigation: This practice has been the main factor to allow the establishment of the coffee plant in marginal areas of low altitude in that the mean air temperatures are high for the usual cultivation of the Arabica coffee [22].

CONCLUSIONS

Coffee is one of the most important commodities traded in the world which is a source of income generation for millions of people around the world. It is grown in more than 60 countries. Currently, the production is challenged by many factors and also there will be constraints that will decrease the production of coffee in the world including Ethiopia. Coffee is produced in the eastern part of Africa in which Arabica coffee is dominantly produced. The production of coffee will be limited as a result of climate change which will highly affect its production since coffee is sensitive to climate change like temperature and precipitation.

Trends in climate change in Eastern Africa shows the increments in temperature and decrease in precipitation which shows variation through different regions of different countries. Different scholars predicted impacts of climate on the production coffee which is the backboneof many countries. According to their prediction, there are many effects on yield loss and quality of coffee because of the rise in temperature and decrease in rainfall and also aggravate the disease and pests on coffee. The influence of climate change may force coffee production to shift current growing area to higher altitudes to satisfy demands. This situation/shifting production area may be challenging because it may consequences deforestation or it may compete with food crop producing area which is very hard especially for developing countries.

As coffee production is influenced by climate change in the future different mitigation strategy should establish to meet the demand of the consumer. Furthermore, emphasize should be given by Arabica coffee growing region which may have already suffered yield losses due to recent Temperature min increases, or may so in the near future. It may give the coffee sector the hard numbers required to encourage the public and privatesectors to invest in climate change adaptation strategies that will better sustain this important industry and the livelihoods of millions of smallholder farmers who depend on it. In general research question is open for how to combine suitability, variability and production analyses for optimum coffee production caused a change in climate change. Another under-studied area is coffee pests. Thus, a 1-2°C increase in temperature would result in large losses from the coffee berry borer, particularly in regions with high-quality Arabica so there is a need to control through intensive investigation. Future work would extrapolate the effects of climate on coffee production amounts and locations to determine the consequences for price and demand.

REFERENCES

1. Gray, Q., A. Tefera and T. Tefera, 2013. Ethiopia: Coffee annual report. GAIN Report No. ET-1302, GAIN Report Assessment of Commodity and Trade by USDA, USA, May 14.
2. Da Matta, F.M., C.P. Ronchi, M. Maestri and R.S. Barros, 2008. Ecophysiology of coffee growth and production. Braz. J. Plant Physiol., 19: 485-510.
3. Camargo, M.B.P., 2010. The Impact of Climatic Variability and Climate Change on Arabic Coffee Crop in Brazil. Review article. Bragantia, Campinas, 69(1): 239-247.
4. Patricia, F., 2011. The Coffee Exporters Guide. 3rd Edn. International Trade Center, Geneva, pp: 247.
5. ICO (International Coffee Organization, England), 2014. Historical data of coffee production 2014. Intergovernmental Panel on Climate Change (ICCP). Climate Change 2014–Impacts, Adaptation and Vulnerability: Regional Aspects. Cambridge University Press.
6. Killeen, J.T. and G. Harper, 2016. Coffee in the 21st century. Will Climate Change and Increased Demand Lead to New Deforestation.
7. Msuya, A.M., 2013. Impact of climate variability on coffee production and farmers coping and adaptation strategies in highlands of Kigoma district, Tanzania. A dissertation submitted in partial fulfillment of the requirements for the degree of Master of Arts in the Rural Development of Sokoine University of Agriculture. Morogoro, Tanzania.
8. Ramirez-Villegas, J., M. Salazar, A. Jarvis and C. Navarro-Racines, 2012. A way forward on adaptation to climate change in Colombian agriculture: perspectives towards 2050. Clim Change. 115(3-4): 611-28. DOI: 10.1007/s10584-012-0500-y.
9. Zullo, H.S. Pinto, E.D. Assad and A.M.H. Ávila, 2011. The potential for growing Arabica coffee in the extreme south of Brazil in a warmer world. Clim Chang. DOI:10.1007/s10584-011-0058-0.
10. Schroth, G., P. Laderach and J. Dempewolf, 2009. Towards a climate change adaptation strategy for coffee communities and ecosystems in the Sierra Madre de Chiapas, Mexico. Mitig Adapt Strategies Glob Chang, 14: 605-625.
11. Laderach, P., J. Haggar, C. Lau, 2009. Mesoamerican coffee: building a climate change adaptation strategy. CIAT, Cali.
12. Dasaklis, T.K. and C.P. Pappis, 2013. Supply chain management in view of climate change: an overview of possible impacts and the road ahead. J. Industrial Eng. Manage., 6(4): 1139-1161.
13. Jaramillo, J., C. Adenirin, K. Charles, J. Alvaro and E. Fernando, 2009. Vega; Hans-Michael Poehling; and Christian Borgemeister. Thermal Tolerance of the Coffee Berry Borer Hypothenemus hampei: Predictions of Climate Change Impact on a Tropical Insect Pest. PLOS ONE, 4(8): 1-11.

14. International Coffee Organization, World coffee trade (1963–2013): A review of the markets challenges and opportunities facing the sector (London: International Coffee Organization, 2014).
15. Gay Garcia, C., F. Estrada and C. Conde, 2006. Potential impacts of climate change on agriculture: a case of study of coffee production in Veracruz, Mexico. Clim Chang, 79: 259-288. DOI:10.1007/s10584-006-9066-x.
16. Davis, A.P., T.W. Gole, S. Baena and J. Moat, 2012. The impact of climate change on indigenous Arabica coffee (*Coffea arabica*): predicting future trends and identifying priorities. PLoS ONE 7: e47981. DOI:10.1371/journal. pone. 0047981.
17. Simonett, O., 1988. Using GIS in a Global Context: The Global Resource Information Database (GRID). Proceedings, Eighth Annual ESRI User Conference
18. Niang, I., O.C. Ruppel, M.A. Abdrabo, A. Essel, C. Lennard, J. Padgham and P. Urquhart, 2014. Africa. In: Climate Change 2014: Impacts, Adaptation and Vulnerability.
19. Williams, A.P., C. Funk, J. Michaelsen, S.A. Rauscher, I. Robertson, T.H.G. Wils, M. Koprowski, Z. Eshetu and N.J. Loader, 2012. Recent summer precipitation trends in the Greater Horn of Africa and the emerging role of Indian Ocean sea surface temperature. Climate Dynamics, 39: 2307-2328.
20. McSweeney, C., M. New and G. Lizcano, 2010. UNDP Climate Change Country Profiles: Ethiopia, pp: 27.
21. Jury, M.R. and C. Funk, 2013. Climatic trends over Ethiopia: regional signals and drivers. International Journal of Climatology, 33: 1924-1935.
22. Haggar, J. and K. Schepp, 2012. Coffee and climate change: Impacts and options for adaption in Brazil, Guatemala, Tanzania and Vietnam. Climate Change, Agriculture and Natural Resource.
23. Mutai, C.C. and M.M. Ward, 2000. East African rainfall and the tropical circulation/ convection on intra-seasonal to inter-annual timescales. Journal of Climate, 13(22): 3915-3939.
24. McHugh, MJ., 2006. Impact of South Pacific circulation variability on East African rainfall. International Journal of Climatology, 26(4): 505-521.
25. Schreck, C.J. and F.H.M. Semazzi, 2004. Variability of the recent climate of eastern Africa. International Journal of Climatology, 24(6): 681-701.
26. Mayer, A. , 2013. Climate change already challenging agriculture. Bioscience, 63(10): 781-7. DOI: 10. 1525/bio.2013.63.10.2PMID:WOS:000325743900002.
27. Power, S., F. Delage, C. Chung, G. Kociuba and K. Keay, 2013. Robust twenty-first-century projections of El Nino and related precipitation variability. Nature, 502(7472): 541-5. DOI: 10.1038/nature12580 PMID: 24121439.
28. USAID, 2013. Uganda climate change vulnerability assessment report.
29. Moat, J., J. Williams, S. Baena, T. Wilkinson, S. Demissew, Z.K. Challa, T.W. Gole and A.P. Davis, 2017. Coffee Farming and Climate Change in Ethiopia: Impacts, Forecasts, Resilience and Opportunities. Summary. The Strategic Climate Institutions Programme (SCIP). Royal Botanic Gardens, Kew (UK), pp: 37.
30. Patricola, C.M. and S.K. Cook, 2011. Sub-Saharan Northern African climate at the end of the twenty-first century: forcing factors and climate processes. Climate Dynamics, 35: 193-212.
31. Conway, D. and E.L.F. Schipper, 2011. Adaptation to climate change in Africa: challenges and opportunities identified from Ethiopia. Global Environmental Change, 21: 227-237.
32. Bunn, C., P. Läderach, O. Ovalle Rivera and D. Kirschke, 2015. A bitter cup: climate change profile of global production of Arabica and Robusta coffee. Climatic Change Springer, 129: 89-101.
33. Ovalle-Rivera O., P. Läderach, C. Bunn, M. Obersteiner and G. Schroth, 2015. Projected Shifts in *Coffea arabica* Suitability among Major Global Producing Regions Due to Climate Change. PLoS ONE 10(4): e0124155. DOI:10.1371/journal. pone.0124155.
34. CTA (Technical Centre for Agricultural and Rural Cooperation), 2014. Climate-smart agriculture in Africa Higman S, Kingdom U (ed.), Anibal, Mozambique, pp: 34-40.
35. Iscaro, J., 2014. The Impact of climate change on coffee production in Colombia and Ethiopia. Global Majority E-Journal, 5(1): 33-43.
36. Jaramillo, J., E. Muchugu, F.E. Vega, A.P. Davis, C. Borgemeister, 2011. Some like it hot: the influence and implications of Climate Change on coffee berry borer (Hypothenemus hampei) and coffee production in East Africa. PLoS ONE, 6(9): e24528.
37. Jaramillo, J., M. Setamou, E. Muchugu, A. Chabi-olaye, A. Jaramillo, J. Mukabana and C. Borgemeister, 2013. Climate Change or Urbanization? Impacts on a Traditional Coffee Production System in East Africa over the Last 80 Years, 8(1).

38. Camargo, M.B.P., 2009. The Impact of Climate Variability on Coffee Crop.
39. Van Rikxoort, H., G. Schroth, P. Laderach and B. Rodriguez-Sanchez, 2014. Carbon footprints and carbon stocks reveal climate-friendly coffee production. Agronomy for Sustainable Development, 34(4): 887-897.
40. Lin, B.B., 2011. Resilience in agriculture through crop diversification: adaptive management for environmental change. Bioscience, 61: 183-193.
41. Vaast, P., B. Bertrand, J.J. Perriot, B. Guyot and M. Genard, 2006. Fruit thinning and shade improve bean characteristics and beverage quality of coffee (*Coffea arabica* L.) under optimal conditions. J. Sci. Food Agr., 86: 197-204.
42. Teodoro, A., A.M. Klein and T. Tscharntke, 2008. Environmentally mediated coffee pest densities in relation to agroforestry management, using hierarchical partitioning analyses. Agr Ecosyst Environ, 125: 120-126.
43. Perfecto, I., J. Vandermeer, A. Mas and L. Soto-Pinto, 2005. Biodiversity, yield and shade coffee certification. Ecol. Econ., 54: 435-446.
44. Davis, A.P., R. Govaerts, D.M. Bridson and P. Stoffelen, 2006. An annotated taxonomic conspectus of the genus *Coffea* (Rubiaceae). Bot. J. Linn Soc., 152: 465-512.
45. Waller, J.M., M. Bigger and R.A. Hillock, 2007. Coffee pests, disease and their management. CABI, UK, pp: 400.
46. Kasterine, A., M. Scholer and J.H. Hilten, 2010. Climate Change and the Coffee Industry. Abstract for trade information services. International Trade Centre, Palais des Nations, 1211 Geneva 10, Switzerland.
47. Garedew, W., B.T. Hailu, F. Lemessa, P. Pellikka and F. Pinard, 2017. Coffee Shade Tree Management: An Adaptation Option for Climate Change Impact for Small Scale Coffee Growers in South-West Ethiopia. Springer International Publishing. W. Leal Filho (eds.), Climate Change Adaptation in Africa, Climate Change Management, DOI 10.1007/978-3-319-49520-0_40.