International Journal of Environmental Monitoring and Analysis
2023; 11(4): 80-88
http://www.sciencepublishinggroup.com/j/ijema
doi: 10.11648/j.ijema.20231104.11
ISSN: 2328-7659 (Print); ISSN: 2328-7667 (Online)

The Current Climate Change Impacts in Arabica Coffee Production and Mitigation Option in Case of Ethiopia: A Review

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To cite this article:
Daba Etana, Dawit Merga. The Current Climate Change Impacts in Arabica Coffee Production and Mitigation Option in Case of Ethiopia: A Review. *International Journal of Environmental Monitoring and Analysis*. Vol. 11, No. 4, 2023, pp. 80-88.
doi: 10.11648/j.ijema.20231104.11

Received: February 16, 2023; **Accepted**: July 11, 2023; **Published**: July 21, 2023

Abstract: The climate change syndrome became chronic problems, making it tedious to give a straightforward diagnosis and solution. Day-to-day weather variability is the most challenging worldwide. Of several sectors facing climate change impacts, the agricultural sector is the most susceptible, dramatically reducing its outputs and outcomes. Severity grows more spectacularly in developing countries such as Ethiopia. The current climate change symptoms in Ethiopia's coffee production are yield reduction, disturbance on physiological and normal growth, quality deterioration, outbreaks of pests that earlier economically minor (diseases and insect pests such as thread blight and thrips) in coffee production and genetic erosion observed at ex-situ and in-situ areas. Arabica coffee is the most susceptible species to climate change, with a rough estimation scenario showing around 40% genetic erosion expected due to climate change if there are no mitigation interferences in Ethiopia. Huge reduction in quality and productivity of Arabica coffee has been significantly observed due to climate change and variability. Majorities of marginal production areas have become less productive and out of production in Ethiopia. Coffee producers enforced to substitute coffee farm with climate change-tolerant annual and perennial crops and other trees which negative affects coffee industry. In addition, the coffee land use system vividly changed the safest and most environmental friendly coffee production system into other intensive and careless production methods due to producers discouraging. However, indigenous farmers' knowledge and recently generated agronomy technologies can be used to mitigate climate change and its effects. Further awareness creation and application of mitigation methods such as agroforestry, shade, intercropping, irrigation, cover crops, different integration methods and genetic improvement or developing climate smart variety are the key solution and the hope for future coffee industry and producers.

Keywords: *Coffee arabica*, Climate Change, Genetic Erosion, Mitigation Method, Production

1. Introduction

The most antagonistic action observed for human welfare, health, peace, and self-dependence in the late 20th century is climate change. It is rapidly distributed over the world and evoked by inevitable factors such as population growth and resource depletion. Climate change has the implication of having negative impacts on systems around the world, with allegations throughout the food system and society [1]. Thus, climate change is an acute long-term concern that is reported as the possibility of temperature increases from 3.6 to 7.2, rainfall reduction, and global warming over the next twenty years [2].

Several weather parameters determine climate change; the most commonly known are: temperature, heat, sea level, wind, relative humidity, and irradiance of rainfall, which are interlinked and indirectly depend on each other [3-6]. In several sectors, agricultural commodities faced substantial risks from climate change because of their dependence on weather variables [7]. Coffee is an internationally known crop that is grown on at least four continents in more than 85 countries around the world. However, the three primary coffee growing and exporting areas are: Central and South America, Africa and the Middle East, and Southeast Asia throughout the world, all of which are in the equatorial region [8].

Currently, more than 141 coffee species are known [9], and Arabica and Robusta coffee cover around 99% of world coffee production and the global market [10]. Arabica coffee covers around 60 to 70% of the world coffee market and production. From these species, Arabica coffee is highly susceptible to climate change. Ten countries are known for coffee production around the world, while Ethiopia is the only country that produces Arabica coffee and is known by its center of origin with huge diversity. It is the first in production from Africa and the highest consumer around the world. Ethiopia is the only country known to drink half of the annual coffee produced. In addition, considerable cultural and historical heritage is associated with coffee ceremonies implemented in the country, which serve as two-thirds of foreign income sources. Despite all these advantages of coffee, current climate change severity poses the greatest threat to the coffee sector.

Several collections are maintained in the research centers, and biodiversity have been reducing each year due to climate change and diseases. Thus, genetic erosion is taking place in areas of the coffee origin due to climate change. Commonly known and economically important coffee diseases in Ethiopia are coffee leaf rust (CLR), *Hemileia vastatrix*; coffee berry disease (CBD), *Colletotrichum kahawae;* coffee wilt disease (CWD), Gibberella xylarioides (*Fusarium xylarioides*) [11]. Similarly, Antestia bugs and coffee leaf miners are considered as a major insect pests of coffee in Ethiopia [12]. However, currently, due to climate change, several insect pests such as ants, blotch minor, skeleton, thrips, coffee berry borer, and disease (threat blight, root rot, and unknown) are become economically important in coffee production [13].

Simulation studies underlines as climate change causes yield reduction and more severe on quality. Model of the current and future coffee production under climate change shows the direction of yield reduction with strong negative impacts especially at higher levels of warming and at low latitudes [14-18]. In addition, climate change will significantly affects the Ethiopian specialty coffee sector and area-specific adaptation measures are required to build resilience [6]. Thus, this review was prepared with the aim of elucidating the current impacts of climate change in coffee sectors and urgent management action in Ethiopia.

2. Arabica Coffee and Climate Change

Climate change is defined as profoundly modified agricultural condition which causes both direct and indirect impacts on conducted activities [18]. Almost it has impact over nature, but level of severity is different among things based on their nature. Majorities of agricultural crops characterizes with adaptable range of weather/climate parameters. Some crops adapted in wide range of agro-ecology; whereas, some crops need specific and narrow adaptation sizes.

Arabica coffee is originated in southwestern montane of moist under natural forest. It is still collecting from the forest, providing good yield and quality under moderate shade condition. Several reports indicated as its narrow genetic distance and adapted to tropical countries with less specific adaptation in condition (Figure 1). Arabica coffee mostly prefer temperature ranges of 18-23 with 1300 o 2200m altitude, and 1500 to 2000 mm of annual rainfall and preferable well distributed at least for six to seven months [19, 20, 3]. The agro-ecology with moist humid is best for coffee production along the specified weather and geographical altitudes. Thus, suitability of specific areas for coffee production determined based on agro ecology and the specified weather parameters. Thus, Arabica coffee is the most susceptible from coffee species [6].

Climate change reducing coffee quality and production which can affects producers to meet livelihood needs [21, 22]. The coffee is highly sensitive to climate variability with respect to productivity and quality [23-25]. Climate variability means disturbed rainfall (less in amount distribution, intensive with ice and snow), agricultural drought (rain interrupted, late rain or early stopping), and extreme weather events affects overall coffee production [22, 26].

Several simulation scenarios of the relationship of Arabica coffee with climate change shows declining in areas of production, productivity, and quality. For instance, Ahmed et al. [1] reported that how climate change influences coffee production in all direction all over the world using data results from 2000 to 2018 years. They described out ten prevalent environmental factors and management conditions were identified in the studies including: (1) geography; (2) altitude; (3) light exposure; (4) temperature; (5) water stress; (6) nutrient management; (7) type of cultivar; (8) pests and disease management; (9) fruit thinning and; (10) carbon dioxide which directly and indirectly affect the coffee production.

The habituation of coffee in highland dramatically changed from previous location to new areas might not suitable earlier. For instance, coffee is limited in majorities of southwester, southern, and very few eastern parts of Ethiopian country since before two decades. Currently, it's about to expanded in some northern parts as form of large scale production and central highland exhibit as glimmer to produce coffee. Despite of these, marginal lowlands areas are about extinct coffee production due to long dry season, drought, and pest problems. This all indicated shifting of coffee geographical locations s result of climate change [9, 27]. Simulation model showed several suitable world classes for coffee production shift after three decades and Gruter et al. [28] reported that coffee may have chance to reduce by 50 percent of the current suitable areas ((Figure 1).

In general, Arabica coffee is need worldwide attention to continue its current productive status to develop climate change mitigation and adaptation technologies by following the outline several strategies. In addition, the mitigation and adaptation strategies implementation levels highly different in between developed and developing countries, huge diversity of the genetic resources dispersed in third level countries like Ethiopia.

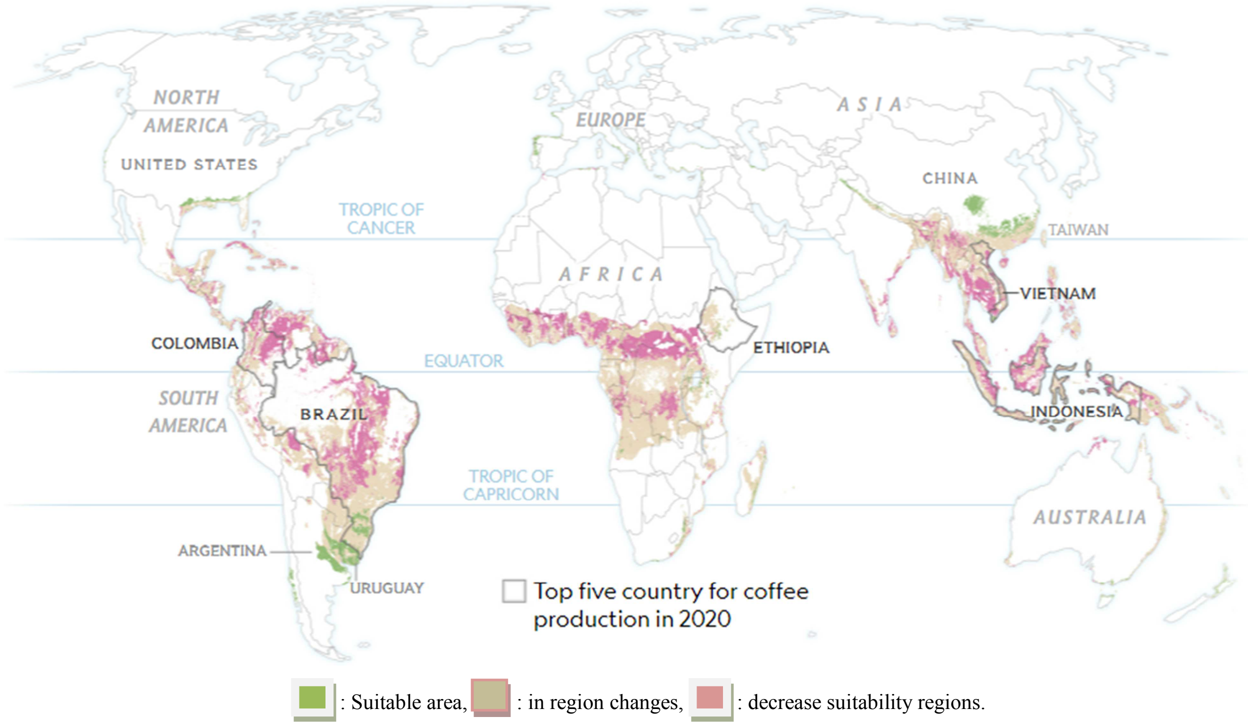

Figure 1. *Coffee suitability modeled continents, Source: Gruter et al. (2022) Overall suitability for coffee.*

2.1. Arabica Coffee Genetic Erosion

Arabica coffee genetic resources are less exploited and difficult to easily manage as other annual crops. Naturally, Arabica coffee is shade loving for normal physiological and quality production. Some modification existed in adaptation of coffee to slightly shade level, without shade, and agro-forestry type. All these adaptations have their own influence on coffee genetic conservation and continuation. Jaleta [29] reported that coffee species are under a severe threat of genetic erosion and irreversible loss largely due to increasing population, expansion of large farms, and crops replacement in addition to climate change.

Coffee germplasms were collected internationally and nationally from Ethiopia by different experts and organizations. However, today, majorities of germplasms counted as genetic resource are collected by national collectors and ex-situ conserved in the last fifty seven years. The most bottleneck to these noble resource is the current devastating climate change.

The total collected of coffee germplasm reported was around twelve thousand and three hundred maintained at different ex-situ and in-situ areas years. However, out of total coffee accessions collected by JARC, around 15.33% were died by different environmental factors [30]. This indicates how much climate change severely affecting Arabica coffee and is resulting genetic erosion in its center of origin.

Several projection clearly reported as climate change has capacity to damage Arabica coffee genetic resources and areas of production. For instance, around 65% of suitable areas of production showed reduction, and at worst scenarios of almost 100% reduction by the year 2080 under the influences of accelerated global climate change in Ethiopia [9]. The prone area of eastern highland known by high quality coffee like Hararghe is under extinction and substitutions with other crops due to frequent drought occurrences [29]. For instance, one of released coffee variety at Haraghe areas and the popular mocha type Arabica coffee of eastern part of Ethiopia is greatly affected by drought stress. Farmers are losing their popular crop due to the recurrent climate change. Currently, the most severe stress conditions (wilting and curling of leaves, loss of coffee crop, and plant death through drought) were recorded in the Hararghe coffee growing environments. Thus, the present climate change needs special attention to intervene its negative impact on genetic resources/germplasms.

2.2. Newly Emerged Coffee Pest and Outbreak

One of the most indirect effects of climate change is offer conducive environments for diseases and insect pests. Such challenges happen all over the world, but more frequently reported in tropical areas. It might be happening due to moist condition is suitable for distribution and reproduction system of insects and micro-organisms. For instance, Locust outbreak damaged majority of Eastern African countries in the last two years. Such condition is different from earlier happen by far. Several scholars justified that an increase in temperature and precipitation levels favors the growth and distribution of most pest species by providing a warm and humid environment and providing necessary moisture for their growth [31]. In agreement, Kifile et al. [32] reported that weather variability in Ethiopia favors the proliferation of certain insect pests and diseases.

Coffee is dwells in specific altitudes, weather parameters, and micro climate which may not suitable for pest/disease surviving [33]. The current climate change has the potential to increases the altitudinal range of the coffee pest as a result of increase temperature and reduces rainfall [34]. Pests and diseases threatening coffee production under the current situation are likely to be aggravated by the effects of climate change and variability and could bring serious problem to coffee sector [14]. Recently outbreaks and increased incidences of pests and diseases across coffee growing regions of Latin America, East Africa and Asia seem to confirm this hypothesis [14, 35, 36].

The recent insect pests and disease outbreak observed in the coffee research field, coffee private farms and farmers field revealing scared the production improvements and continuation. Coffee thread blight considered as non-economic important for the last four decades in coffee research field and farms of Ethiopia; but, currently it is one of the most harm full comparable to coffee berry disease especially at moist and mid altitude areas. Thread blight causes negative impact on biological and yields potentials parts of coffee [13].

a: Showed normal field before affected by thrips during the dry spell

b: Showed coffee tree affected by thrips during the dry spell

Figure 2. *Coffee field affected by Thrips in mid of April, 2022 at JARC, Ethiopia.*

The other pest directly related with climate change and sporadic drought is outbreak of insect pests in coffee farms. For instance, Thrips is considered as less harmful and controlled naturally earlier before two to three years. However, currently it is one of the most powerful full insect pes to reduce coffee yield. It is mostly outbreak by following the interruption of rain after first onset of raining. Such condition is very suitable for this insect to affect coffee leaves (Figure 2b). The field shown under Figure 2b had taken from JARC agronomy site during early April, 2022. Totally, the leaves affected and seems as burnt by fire, and loose turgidity compared to normal field (Figure 2a).

Earlier the most common known and called cancer for coffee trees in Ethiopia is wilt disease caused by Gibberella xylarioides (Fusarium xylarioides). Recently, root rot (Armillaria heimii) became an important and devastating disease to coffee trees in coffee farms. The specific symptoms of coffee root rot are wilting of leaves without change into yellow within short period of time, gradual drying of branches, and stem with cruck vertically on coffee trees (Figure 3).

Figure 3. *Root rot devastating coffee field from lowland to highlands, Ethiopia, 2022.*

Coffee leaf rust is more severe at lowland earlier; but, now started devastating from mid to highland due to high temperatures and moisture create suitable for surviving of the virulence. Figure 4 shows the incidences and abundances of leaf rust on coffee varieties at Jimma area which is categorized under mid altitudes. Such condition indicates the current climate change impact and needs cooperative work of different departments to minimize the threat of climate challenges happen in coffee sectors.

2.3. Land Degradation

One of the most challenges of climate change is land degradation. Productive land is the only solution directly or indirectly for all living organisms. Climate change causes land degradation through unsustainable and intensive land use practices, decreasing the protective plant cover and facing the fertile soil to the high rainfall intensity [37]. For surprise, around 12 ton ha^{-1} and totally 2 billion ton soil lost annually from Ethiopia highland which estimated in cost of 1 billion USD wealth is lost per a year [38, 39]. Even though land degradation depends on slope of farm land, intensive farming, and deforestation which mention as center of climate change, still shared huge role in all soil production depletion. Further, absence of trees and shifting cultivation, over grazing, crop rotation, unexpected wind, and intensive rainfall common example of climate change factors causes land non-productive.

3. Climate Change Projection in Arabica Coffee

Ethiopia is one of the key player in the global best quality coffee providers; whereas, the country markets coffee as distinct based on microclimatic conditions, native heirloom varieties or landraces and other socio-environmental factors. Biophysical parameters determined by suitability, quality contents, productivity, and sustainability of coffee production. Thus, to touch the optimum adaptation extent and potential, simulation model efficiently generates information.

There are different projections reported regarding the current and future coffee production areas while the material, inputs, and techniques of users were varied. For instance, Bunn et al. [15] and Moat et al. [3] projected as opportunity of coffee suitable areas increase in the future and go up at mid highland of the country. However, these studies did not consider individual coffee types, with impact studies on wild Arabica coffee showing significant impacts. In contrary, Chemura et al. [6] simulated base on biophysical showed decline under climate change except for Nekemte, which is projected on average to increase its suitable areas. Some countries of southern and northern borders (e.g. Southern Brazil, Uruguay, Argentina, Chile, USA, East Africa, South Africa, China, India, New Zealand) may have chance to benefit from climate change due to increasing minimum temperatures of the areas [28].

Model studied to predict suitable areas for coffee revealed only 27% is suitable for coffee including suitable to marginal and specialty in Ethiopia [6]. All the scenarios depicted on Figure 4. Over all, it showed dynamics of suitability in areas of production except around southwestern parts of the country such as Nekemte. Depending on drivers of suitability and projected impacts, climate change significantly affect the Ethiopian coffee sector and area-specific adaptation measures are required to build resilience [6].

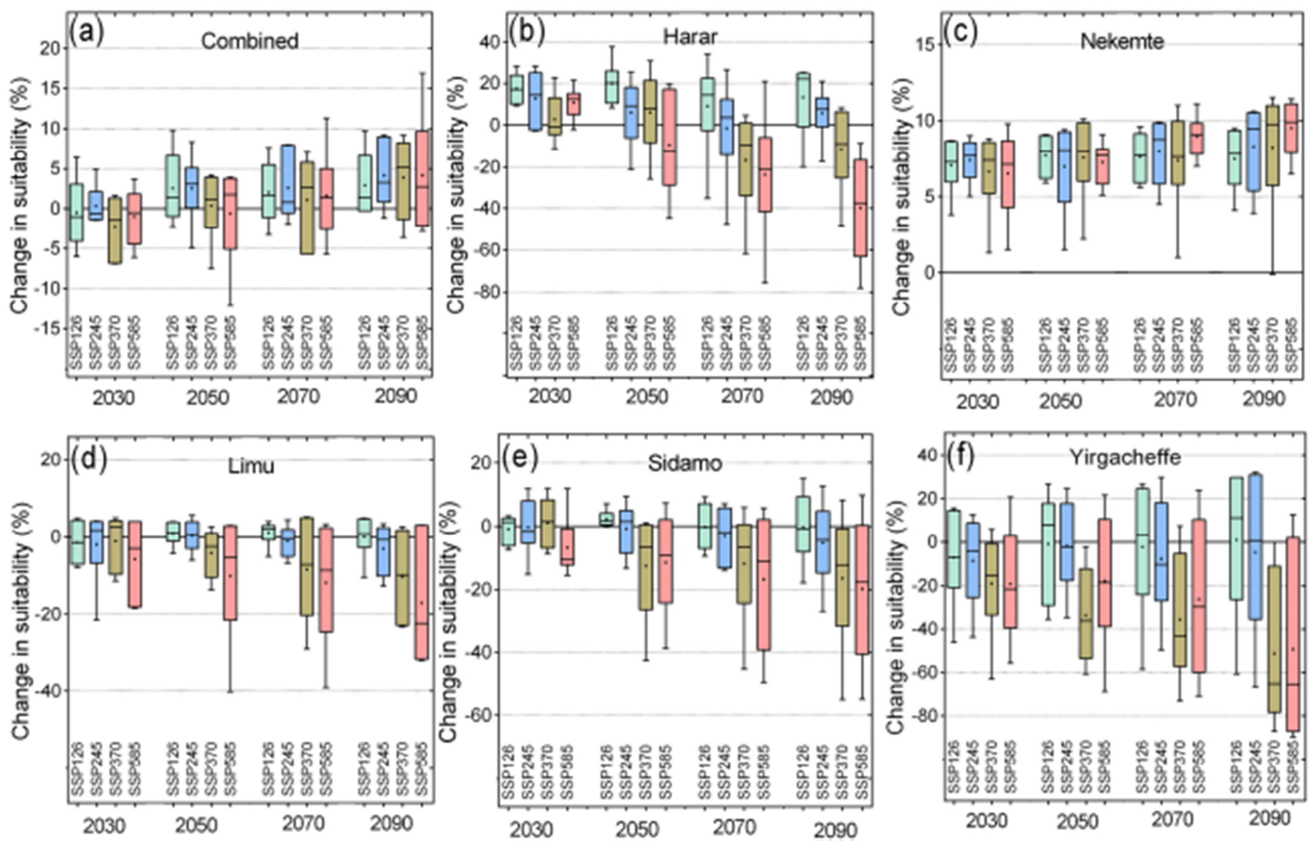

Figure 4. Impacts of climate change on coffee suitability in Ethiopia by 2030s, 2050s, 2070s and 2090s. Te bar plots show the range of projected changes using the ensemble model and the variability from the six GCMs (Source: Chemura et al., 2021).

4. Multi-Dimensional Impacts of Climate Change in Coffee Production

More than two ways interactions on the same object and makes divert from earlier output are categorized under multi-dimensional negative impacts. As similar to other crops, coffee correlated with several parts of social life, and carry burden for life continuity in the biome which exposed it to different direction of climate change. Climate change affects directly coffee growth and physiology, quality and diminished expected yield. Indirectly, it affects natural resources such as disturb conducive agro-ecologies and shade trees, reduces soil nutrients and deplete soil water table, quality deterioration due to high temperature, unable of conducive areas for coffee production, increasing immigration and migration of human power, reduces suitability areas contributes for coffee production improvements and sustainability.

Climate change causes either of individual or group of things affected in coffee production. Occasional intensive rainfall observed and causes soil loss witch significantly affect crop production. In addition, wind erosion also causes soil degradation around the lowland areas. Several ways of soil degradation causes directly and directs nutrient loss from the field of coffee. Thus, continues field with less management such as shade problems, less soil and water conservation structure causes danger in coffee production field; also, expose of coffee field to erosion, full sun, and highest temperature affects soil water table and make less than 40% of soil moisture is less than critical levels affects overall growth activities.

Coffee is very sensitive to micro climate viscosity. Agro ecology is major factors to modify the micro climate of coffee. Humid moist with less frost or not temperature less than 15 °C and not above 26°C is with relative humidity between 40 – 60 create suitable micro climate. Climate change disturbs such conducive condition and affects normal coffee growth and physiology.

Multi-dimensional impacts reduces quality constituents of Arabica coffee. Majorities of its biochemical qualities filled within long maturation period of around 8^{th} months. Obviously, Arabica coffee is known and cherry ripe between 32-35 weeks under normal condition. This, duration defined with different growth stages and duration. If ripped before the expected physiological fruit growth due to temperature increment, the constituents of the fruit deteriorated which leads poor quality at the end stage.

5. Mitigation Methods

Urgent mitigation methods for climate change effects in coffee production are mandatory; these can be in the form of temporary and permanent solutions. Pre-condition strategy for climate change alleviation is the integration of responsible bodies from top to down [40]. Several mitigation methods such as resistant varieties, on time information, forecasting the weather condition, inform the stakeholders, mulching, irrigation, soil and water conservation practices, harvesting rain water, cropping system, and intensive suitable production system [5]. Development of adapted and resistance or tolerant variety may request much time to deliver for users and to overcome the alarming issue of climate change. Few of urgent climate change alleviate methods were described below.

5.1. Cultural Practices

Implementation of cultural practices in coffee field plays several roles in mitigation of climate change such as intercropping, hard, and soft pruning, renewing, stem fungus removing, digging, composting, weeding, and others contributed in climate change mitigation. For instance, Ethiopian coffee producers culturally remove apical of coffee seedling planted after a year. This helps to reduce over elongation and improve vigorousity growing of seedling. In addition, weeding has huge contribution in to reduce evaporation and nutrient completion which has huge contribution to climate change mitigation methods [41]. Such practices are applying directly or indirectly by producers. Immense of challenges are happening in the coffee production is due to disturbed of the naturally adopted production system and replaced by intensification and mono-cropping system without compatibility of its origin. Agronomic practices in coffee field serve to buffering impacts of weather variability. As more intensified form (full-sun mono-crop systems) and diversity of cropping system lost, weather variability increase, and disturb morpho-physiology of coffee [40].

5.2. Shade and Agro Forestry Practices

Agro-forestry practices are sharing the most role in buffering impacts of climate change in coffee production and have incredible capacity into balance the micro climate and environmental weather condition. The sensitivity of coffee to increase temperature condition enforce to develop and design climate-smart practices, and adaptation strategies in coffee settings. Coffee species showed it is heliophobic type in nature; however, through some genetic and management improvements, recently open sun production substituted natural habit of the crop. However, such production system causes several changes and scaring for future coffee production, productivity, quality, and genetic conservation. Thus, it needs to come back to its original production system such as production under shade and agro forestry are urgently needed.

Shading is an important practice which provides direct important by diffracting direct sun light and reduce photo oxidation, and indirectly benefiting agro forestry, tree species, improve soil fertility, reduces erosion, and soil micro and macro fauna diversification [42]. Shade has potential to raise minimum temperature by 2˚C; while, decrease extreme by 4.8˚C, which is desirable in many marginal coffee growing areas [24, 42- 44]. Thus, sun radiation was reduced by 60% under shade trees, as a result coffee light-use efficiency increased by 50% and leaving net primary productivity fairly similar [45].

Shade has important role into balance day and night heat fluctuation in coffee field. Not only drought is dangerous for coffee, while frost of temperature less than 12˚C directly diminish morpho-physiological growth. For instance, conservation of heat during the night or cool during dry season effectively and prevents temperature calamity, which is necessary for the reproductive growth processes in coffee system [46-48]. In coffee system, the most boring and worry is mean temperature is reaching the maximum temperature requirements for optimum growth and quality of Arabica coffee (23˚C) [49].

The shaded coffee field providing promised result in coffee physiology by reducing temperature up to 4 ˚C - 5 ºC and reducing wind speed, improve relative humidity, and changes in aerodynamic roughness of the cropped area as compared to non-shade coffee field [4]. The micro climate and soil temperature have potential to manage shifting of areas of production upwards altitudinally by 150–200 [4]. These alterations would decrease leaf-to air vapour pressure deficit, which in turn would allow longer stomatal opening (thus favoring CO_2 uptake), without a proportional increase in transpiration rates [50].

Ethiopian coffee production system classified into five based on intensity of managements and related with agro foresting system [3, 51]. Those are forest (<5%), semi forest (5 – 10%), garden coffee (35- 40%), plantation (~10%), and semi plantation (10 – 20%). Forest coffee production system is the system where less management and natural forest trees found in intensity, while, semi forest has more managed and plantation with few of improved production technologies, garden is the most frequently diversifying and found around the backyard of farmer house with good management and intensive agro-forestry by inter-cropping with staple crops such as taro, enset, leguminous, avocado, mango, etc according to their adaptable agro ecologies. While, coffee plantation system limited at a hand of private farmers in Ethiopia, and semi plantation is one of government strategy in the form of cluster farming by neighbor farmers. This is new system semi plantation varied by intensive of inputs application only from plantation.

All coffee production system practicing in the country has own advantages and disadvantages to alleviate climate change impacts in coffee production. Forest and semi forest system provides huge conservation of shade tree species and even coffee species and coffee genotypes. It categorized under single agro forestry which means coffee with tree only, rather than multi and intensive agro forestry which rose as drawback of the systems. In other direction, the garden production systems showing multi system of agro forestry: coffee + shade tree + bee hive + food crop + animal feed + soil fertility and moisture improvement + medicinal plant relatively observed. Plantation is extremely focusing on coffee productivity improvements and mostly single agro forestry system (coffee and shade trees) found in this production. In general, in all coffee production system in Ethiopia, agro forestry system is a basic and has its own procedures how to one hand over into other shade types and species. The simple procedures implementing in shade development of Ethiopian coffee production systems are hat construction (a), temporary shade (b), and permanent shade (c and d) (Figure 5).

Each level has its own role and steps in shading coffee trees starting from planted seedling to productive stage of coffee. Hat shade constructed first year of planting to keep seedling from desiccation due to winter sun effects. Temporary shade planted in the field during the summer or coffee seedling planting time and able to give shade province for the coming next winter season. Similarly, permanent shades species such as Acacia abysyinica, Albizia species, and others planted with recommendation spacing as described in Table 1 to provide shading for long harvesting seasons.

Figure 5. *Different shade type practicing in coffee production under shade in Ethiopia: a) hat shade, b) temperory shade, c and d) permanent shade tree species.*

Table 1. *Shade species with spacing recommendation with coffee plant in the field.*

Shade types	Spacing (meter)	Per hectare population
Acacia species	20×20	25
Albizia species	20×20	25
Milecia species	8×8	156
Cordia africana	16×16	39
Erthtrinia species	16×16	39
Lucinia species	6×6	277
Susbania susban	4×4	625

Furthermore, crops such as banana and enset can be used as shade, while it should practices with recommendation and intensive managements. Overall, shade is guarantee of Ethiopian coffee production sustainability and quality. Open production system not started in the country, while very few of supplemental and full irrigation system started in northern part of the country.

6. Conclusion

Climate change and its impacts is dramatically increasing worldwide. Majorities of susceptible sector severed and in some areas about extinction. Agriculture is the most susceptible sector to the climate change and dangerous for developing countries due to a round 85% depends on rain fed agricultural system. Under agricultural scope, several crops species responses to climate changes varies and mitigation system also different. However, among coffee species Arabica coffee is very sensitive to climate change and needs especial attention to continue its production and sometimes how to protect from genetic erosion. Several modeling scenarios showed Arabica coffee is more susceptible to climate change and need urgent investigation to develop mitigation for short period and adaptation technologies as long period improvements. Currently, climate change is observed via major weather parameters such as reducing rainfall and its distribution, increase temperature, and light changes widely revealed in coffee growing condition. Thus, it needs modern and cultural methods which have potential to manage climate change as short and long mitigation options.

The most important and recommended technologies to overcome climate change effects in coffee production are: cultural management system, and the integrations of soil and water conservation practices according their compatibility to agro ecologies. The short period of mitigation systems coffee based agroforestry such as shade (temporary and permanent) and intercropping are imperative. Long method technologies application should follow the short method mitigation to realize sustainable coffee production and industry in the country.

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