



Review Article

Climate Smart Coffee (*coffea arabica*) Production

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Abstract: Climate smart coffee production is indispensable measure to withstand climate change challenges; since, Climate change is a worst problem that the world is facing and will result incredible situation unless adaptation and mitigation measures are taken. The review was prepared to access the effect of climate change on coffee (*coffea arabica*) production and the possible adaptation and mitigation practices to withstand the challenges. The most frightening impact of climate change on coffee producing regions have been identified as being at a high risk and need to make extra efforts to prepare for the future thereby to maintain sustainable productive coffee production. It is possible to withstand the negative impacts of climate change by different adaptation and mitigation practices; such as, Shade use and reforestation, crop improvement, coffee-banana intercropping and other conservation practices was included. Comprehensive accomplishment of these practices helps to alleviate the climate change impacts. Some gaps was identified regarding with shade tree variety development and determining the appropriate shade level, identification of drought resistance genes from coffee arabica and coffee-enset intercropping.

Keywords: Climate Smart Coffee, Climate Change Impact, Adaptation, Mitigation

1. Introduction

Climate change is the worst situation that the glob is facing, and it will continue to change throughout the 21st century and beyond. Important factors that play a role for climate change are, rising fossil fuel burning and land use changes are continuing to emit, and increasing quantities of greenhouse gases into the Earth's atmosphere. The rising greenhouse gases [carbon dioxide (CO₂), methane (CH₄) and nitrogen dioxide (N₂O)] in the atmosphere can increase the amount of heat from the sun withheld in the Earth's atmosphere, that would normally be radiated back into space, [34]. There are climate change action represents both a potentially catastrophic scenario for all living species if humans don't change their ways, and a call for vigorous action towards a greener, more efficient economic model. Rising temperatures, new precipitation patterns, and other changes are already affecting many aspects of human society and the natural world. Climate change is transforming ecosystems on an extraordinary scale, at an extraordinary pace. The main characteristics of climate change are increases in average global temperature (global warming); changes in cloud cover and precipitation particularly over land; melting of ice caps

and glaciers and reduced snow cover; and raise in ocean temperatures and ocean acidity due to seawater absorbing heat and carbon dioxide from the atmosphere [16].

It is not surprising that 75% agriculture has received a great deal of attention in recent times when action for tackling climate change has been placed at very top of the world's political agenda; because of, more human beings derive their livelihood from agriculture than from any other economic activity and the majority are self-employed subsistence farmers living in the tropics, [16]. According to [34], [16] report, the adverse effect of climate change on agriculture will occur predominantly in the tropics and subtropics mainly at sub-Saharan Africa and, to a lesser extent, South Asia. This means the most alarming effect on coffee producing regions have been identified as being at a high risk and need to make extra efforts to prepare for the future. In the case of the coffee crop, the expected impacts are negative due to the increase in temperatures that will provoke changes in the crop cycle, with consequences ranging from higher vulnerability to some diseases to more complicated harvesting and post-harvest tasks [20].

The most important challenge regarding with the climate change on coffee production and quality assurance is the

outbreak of coffee pests reduction of arable land. The interaction of climate and coffee berry borer greatly influences projected outcomes. Recent evidence shows that climate change is having substantial impact on the areas suitable for cultivation of Arabica coffee in the major growing regions, including the East African Highlands region [14]. This could lead to the establishment of coffee plantations in new areas and potential conflicts with other land covers including natural forest, with consequent implications for biodiversity and ecosystem services, [25]. The other decisive impact of climate change is the outbreak and dissemination of coffee leaf rust. The reduction in coffee yield and quality have had direct impacts on the livelihoods of thousands of smallholders and harvesters. For these populations, particularly in Central America, coffee is often the only source of income used to buy food and supplies for the cultivation of basic grains. As a result, the coffee rust epidemic has had indirect impacts on food security, [2]. As [22] and [11] reported, by 2050, the area suitable for coffee cultivation decreases by 50%. Globally, about 56% of Arabica landscapes are forested. Regionally, the risk from deforestation linked to Arabica cultivation is highest in the Andes and Southeast Asia, while Brazil and East Africa represent potential expansion areas with the lowest risk of deforestation. Coffee quality highly affected with temperature increase above 23°C. As temperature rises, coffee ripens more quickly leading to a fall in inherent quality [22].

There is possibilities and mechanisms to cope with climate change and maintain sustainable production of coffee (*coffea arabica*) though the climate changes entirely affect coffee production in the coffee sector throughout the world. Climate smart coffee production is the day-to-day heart beats of 75% world's coffee Arabica producers through different mechanism. To a limited extent, progress towards mitigating the effects of climate change is of course assisted by adhering to Good Agricultural Practices or GAP, which is further in line with coffee production, good farming practices automatically help conserve soil and water and in so doing also make it easier to adapt to global warming whilst at the same time lessening its impact. Afforestation and shade tree planting also another instrument to alleviate climate change problem. reforestation, boundary tree plantings, and avoided deforestation could sequester significant amounts of carbon. Reforesting with forest or coffee agro-forestry systems on degraded lands could also improve other ecosystem services, such as soil and water conservation, and reduce land degradation. Boundary tree plantings is also one part of reforestation and can sequester substantial quantities of carbon [31], [9].

Indeed, efforts regarding with mitigation and adaptation are on the way to maintain and/or minimize the impacts of climate change on coffee Arabica production. Among those conservation agriculture (tillage, cover crops, and rotation), irrigation, agro-forestry, and soil conservation structures, are inclusively known as climate-smart agriculture techniques. Hence, this review/current topic aimed to assess climate-smart coffee (Arabica) production.

2. Climate Change and Coffee Production

Definition of terms

According to [18] Climate in a narrow sense can be defined as "the average weather, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years" and the classical period for averaging these variables is 30 years. The term climate change is also defined as change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer [18]. [5] also defined the term climate change as those changes that have been observed since the early 1900s and includes anthropogenic and natural drivers of climate. The world's average temperature is rising, mainly due to natural internal processes or external forcing, or to persistent anthropogenic changes in the composition of the atmosphere or in land and human influences through emissions of greenhouse gases such as carbon dioxide (CO₂) and methane (CH₄). Now a days, about 6.5 billion tonnes of CO₂ are emitted globally in each year, mostly through burning fossil fuels. Changes in land-use mean a further net annual emission of 1-2 billion tones of CO₂. Such increasing concentrations of greenhouse gases in the atmosphere since the industrial revolution have trapped more energy in the lower atmosphere, altering global climate [5], [13].

Physical changes predicted by commonly used future climate scenarios, of relevance for agricultural activity, include: increases in air and soil temperatures, changes in CO₂ concentrations in the atmosphere, sea level rise, changes in the hydrological cycle and in water quality and availability, intensification and increase in frequency of extreme weather events, including droughts and floods, changes in the altitudinal level of dew points, and others. Some of these changes are gradual and unidirectional, that is, they will show over time at a rate still uncertain but with a known direction. Within this context, climate changes anticipated during this century may exert additional pressure on environmental conditions under which agriculture activity has developed, and if not properly addressed may ultimately result in significant economic and social impacts [35].

3. Impact of Climate Change on Coffee (*coffea arabica*) Production

There is no debate that climate change affecting both Arabica and robusta producers specially small-scale produces who has no technologically farming system. In these case, the coffee crop, with consequences ranging from higher vulnerability to some diseases to more complicated production chain [17]. Climate change is just one of numerous factors that may affect global coffee production, mainly smallholders farmers who produce the majority of the world's coffee [22].

Coffee plants are also quite sensitive to changes in

microclimate. High temperatures are known to disturb plant metabolism. Open-sun cultivated coffee provoked leaf exposure to high irradiance and the absorption of much more energy than that usable by photosynthesis which intern the energy overcharge and to an overheating of leaves [13]. Above 23°C, fruit development and ripening are accelerated, leading to loss of quality; below 18°C, growth is depressed [26]. Furthermore, moderately shaded Arabica coffee plants have photosynthetic rates three times higher than coffee leaves under full sun [10]. The optimal temperature range for Arabica coffee is between 18°C and 21°C and shade helps keep the coffee cooler during the day and warmer at night. Studies indicated that at temperatures above 24°C, the net photosynthesis of coffee decreases markedly, approaching zero at 34°C, hinder the development and ripening of cherries and when continued, it could result in reduced growth or even in yellowing and loss of leaves [24], [15].

On the other hand, with a mean annual air temperature below 18 °C, growth is largely depressed. Occurrence of frosts, even if sporadic, may strongly limit the economic success of the crop [7]. High soil temperatures increase the rate of evaporation and organic matter breakdown. This will lead to poor soil structure and increased susceptibility to erosion [23].

Although the optimum rainfall requirements are between 1500mm and 2000mm per annum [26], overall drought and unfavorable temperatures are the major climatic limitations for coffee production. These limitations are expected to become increasingly important in several coffee growing regions due to the recognized changes in global climate [10]. Water availability from precipitation may affect several key functions for the crop plant. First, an extended period of drought is required for the flower buds to form. The flower buds then open simultaneously in response to sporadic dry-season rain and remain receptive to pollination for 48 hours after bud opening. Water availability has also been found to affect the maintenance of maximum photosynthetic rates, high fruit set levels, and fruit size. Coffee phenology is therefore vulnerable to both the quantity of precipitation and the timing of precipitation events [24]. Strong rains interrupt coffee flowering, flooding and destroy the branches. The changes in the rainy season will cause major problems for drying and processing reducing quality and consequential marketability of the coffee. Sporadic rainfall results in random flowering, with flowers and berries at different stages of growth being on the same primary branch, flower drop and biennial bearing, [23]. The unpredictable rains will also affect coffee to flower at various times throughout the year, causing the farmers to harvest small quantities continuously. Increased drought and sunshine can induce the premature ripening of the beans, with sufficient quality loss as well as the yield [26]. Drought also affect the physiological activity of the Arabica plant causing a reduction in photosynthesis processes [15].

The most decisive climate change impact on coffee production is the outbreak of disease and insect pests and the aggressiveness of the existing pests. The most significant coffee pests which becomes series and damaging with climate change leaf rust (*Hemileia vastatrix*) and the coffee berry

borer (*Hypothenemus hampei*) [8]. Coffee Leaf Rust which is favored by high temperatures becomes more series disease and affects coffee in high altitude areas [23]. The area affected by the coffee berry borer has gradually increased over the past decade up-to-date. It had never been reported in plantations above 1,500m until 10 years ago in Arabica coffee. It was predicted that coffee berry disease can expand its distribution under the four possible climate trajectories, potentially affecting $77.8 \pm 1.7\%$ of Arabica and up to $93.02 \pm 1.3\%$ of Robusta plantations [25]. The pests are reported at higher altitudes in the coffee producing Ethiopian highlands due to the rise of temperature. Small-scale coffee producers are likely to be hardest hit because they rely more heavily on natural resources for survival and have little capital to invest in costly adaptation strategies and/or pest and disease management. Pests and diseases, however, may grow much quicker ever than before [13]. Coffee berry disease (CBD) is also favored by high precipitation and low temperature which becomes more severe than ever; change in temperature will affect insect pest dynamics, such as minor pests may become major pests; e.g. thrips [23].

Night minimum temperature have risen by 1°C over the last 50 years leading to increased cloudiness in atmosphere and thereby increases in pest pressure. Incidences of pests and diseases result in decrease of coffee quality and viability of the product. Also water stress affects the physiological activity of the Arabica plant causing a reduction in photosynthesis [15].

The other challenge of climate change is the loss of suitable land for *coffea arabica* cultivation. The rising of temperature render to a certain production areas less suitable or even completely unsuitable for coffee growing, production may have to shift and alternative crops will have to be identified, [19]. The Arabica variety could lose 56% ($\pm 7\%$) of the areas currently suitable for its cultivation by 2050 (particularly in Brazil, East Africa, and Madagascar), with only a small gain of new suitable areas (9% ($\pm 1\%$)) [25]. A 3°C rise of temperature in this century, translates to the lower limit of coffee rising by 10 to 20 ft per year, [5]. A shift in climate and agricultural zones towards the higher altitudes, [23] changes in production, patterns due to higher temperature, changing precipitation patterns, increased vulnerability of the landless and the poor. The average production areas of coffee Arabica and Robusta 57% and 50% respectively are currently exposed. Under an 8% attack rate scenario, only one of the four climate models predicted a net forest loss for Arabica which is 1.2 million ha [25].

A shifts in suitability, another consequence is the proliferation of pests to areas where coffee is grown at relatively high altitudes and previously therefore not regarded as at risk, are now become the most series [26]. Depending up on the above challenges due to climate change, in 2020, coffee production would decline by 34%, reducing profits of US\$200/acre, to less than \$20/acre. Yield declines of Arabica are virtually certain in a warming world because it is a montane species, not adapted to high temperatures [5].

4. Climate Smart Activities Possibly Implemented in Coffee Production

Different authors reported various mechanisms which are possibly applicable to withstand climate change on coffee production and quality assurance. In this regard, measure that should be undertaken are briefly discussed below.

Adaptation: Is commonly applicable by coffee producers both to reduce the negative impacts of climate change and benefit from new opportunities provided from it. It can be enhanced by increasing the resources and knowledge of farmers and by supporting individuals and organizations in responding appropriately to climate change risks [13]. This approach is more positive and may be easier to engage stakeholders by discussing opportunities to increase their resilience, rather than viewing them as victims of climate change. Adaptation for coffee production can be addressed in a number of ways, which can be categorized as short-term and long-term. Short-term adaptation strategies include better farming practices, calculating and reducing the on-farm carbon footprint, and determining the feasibility of creating carbon sinks [22]. Long-term strategies includes linking producers especially smallholders, with the carbon markets to exploit carbon footprint opportunities, capacity building, mapping of climate data, improving soil fertility, examining different production models, developing/planting drought and disease resistant varieties, improve framework conditions for adaptation to future climate risks, and financing mechanisms [22], [12].

Mitigation: Activities that reduce, prevent, or remove greenhouse gas emissions and therefore reduce climate change. The strategies also includes reducing the contribution of coffee production to greenhouse gas emissions, this is primarily a function of the carbon footprint of coffee production and sequestration of carbon in the shade trees or forest areas of the coffee farms, the conservation of existing [8]. Short-term mitigation strategies include building potentials to reduce climate change impacts [22].

Resilience: The term resilience has become a heavily used term and, like 'sustainability'. The compressed definitions of resilience according to [13] is the capacity to absorb change (having an ability to withstand climate change), the capacity to adapt to change and the capacity of coffee producers to learn about what needs to be changed and how to implement these changes.

4.1. Shade Use and Reforestation

It is often assumed that a coffee tree shade system is beneficial ecologically as well as economically [29] though a significant decrease in coffee yield. Shade trees are also used to reduce air temperature by about 4°C at midday and biennial bearing, overproduction and die back, absorbing air carbon dioxide and store it within the plant, conservation of soil moisture and soil erosion and inhibit weed growth [29], [23]. Shade may be beneficial to reduce extreme temperature and rainfall as well as regulate fruit bearing. Shade trees also

reduce excessive light, mulch the soil via their fallen leaf, reduce soil temperature and light intensity, increase the relative humidity of the air. Optimal shade levels are likely to be below 50%, especially for coffee that receives fertilization or supplemental irrigation [36]. High cup quality and large bean size is the characteristics of coffee grown under shade than coffee grown in open-sun though the overall yield reduction and high severity of disease (CBD) was reported. Rate of photosynthesis (A) and Fv/Fm were higher for shaded plants than for plants in direct sun light [4]. Leaf temperatures under all shading regimes were cooler than coffee's grown under full sun [33]. Coffee agroforests may be important for the conservation of biodiversity within forest fragments. In such way, shades are used as a shelter for beneficial insects and vertebrates [30]. In degraded areas coffee shade trees would result in highest mitigation potential, reforestation with coffee agro-forestry systems results additional benefits that are more important for the local livelihood needs, such as income generation from coffee production and capacity strengthening for improving coffee productivity and adaptation to climate change [31].

Coffee plants grown in the shade suffer less from environmental stresses resulted from climate change and have higher biochemical and physiological potential for carbon fixation and produce larger and heavier beans with better taste quality than coffee plants grown in full sun light [4].

4.2. Genetic Improvement

Developing environmentally friendly, stable and drought resistance variety in coffee production is a basic task to withstand climate change challenges even though due to the complexity of the trait, integrated approaches may be more relevant [28]. Like many plant species, coffee displays a diversity of acclimation mechanisms and/or resistance genes to avoid and endure drought and heat stresses although the molecular mechanisms underlying the adaptation of coffee plants to drought are largely unknown [32].

A harmonizing approach which helps to develop plant performance for drought-prone area requires evaluation and selection of traits that are used to drought tolerance. Some of important traits which manifest resistance to drought include water-extraction efficiency, water-use efficiency (WUE), hydraulic conductance, osmotic and elastic adjustments, and modulation of leaf area. Most of these traits are complex and their control and molecular basis is not well understood [28]. Morphological traits such as leaf area and root mass to leaf area ratio were not associated with that response. Instead, the much deeper root system of the tolerant clones enabled them to gain greater access to water towards the bottom of the pots and, therefore, to maintain a more favorable internal water status longer than in drought-sensitive clones. Root characteristics and growth play a crucial role in maintaining the water supply to the plant, and drought adapted plants are often characterized by deep and vigorous root systems [7].

The range of response of coffee varieties to drought is a complex; but, in some countries, research on developing

drought tolerant coffee varieties for climate change adaptation has started. In Kenya and Uganda, basic research is ongoing whereby coffee genotypes are being subjected to drought and heat stress by denying them sufficient water in a greenhouse to [7]. [27] were compared two commercial cultivars for the molecular responses to drought of *Coffea arabica* grown in the field under control (irrigation) and drought conditions using the pyrosequencing of RNA extracted from shoot apices and analyzing the expression of 38 candidate genes and genes with induced expression under drought conditions. Twenty-five genes showing up-regulated expression profiles under drought conditions. Spontaneous mutations manifesting desirable characteristics have been cultivated and exploited for cross-breeding. Mutants genotypes include Caturra, a compact form of var. Bourbon; Maragogipe, Typica (with large beans), San Ramon, a dwarf Typica and Purpurascens, with purple leaf forms; These have been used to develop germplasm evaluation and characterization of genetic variability in adaptation to environmental change and development of improved crop varieties [32].

4.3. Coffee-Banana Intercropping

Intercropping coffee with bananas potentially contributes to climate change adaptation through increasing the appropriate microclimate for coffee growing. The dual advantages of bananas include provision of shade, controlling stomata closure during extreme water deficit and reducing transpiration, which allows banana to remain highly hydrated under drought stress. Banana intercropping is more advantageous so that the banana plant competes less with the coffee plant for water than some other shade trees [14].

In addition to the socio-economic advantages of banana-coffee intercropping, there are a number of benefits of biophysical interactions, continuous ground cover keeping low soil erosion, stabilize or increase coffee yield and quality [21]. Intercropping is an advantageous strategy to cope with the decreasing land availability and provide mulching so as to suppress weed and increase soil moisture [1]. Banana shade reduces the air temperature in the coffee canopy by over 2°C. Coffee grown under banana shade generally produces heavier and larger cherries due to reduction of overbearing, and buffering against biennial fluctuations in coffee yields and the taste of processes product is therefore better, and farmers can earn a higher price [14].

4.4. Other Conservation Practices

Mulching with different grass species and crop residues potentially provide both nutrients, soil moisture and reduce evaporation. Cover crops planting in similar manner, also improve soil moisture availability, nutrient enhancement and serve as shade tree [29].

Rain harvesting is one of important mechanism to cope with water deficiency (drought season) thereby to apply as irrigation. Conserve all the rainy water by forking, digging terraces and mulching which also prevents soil erosion before

coffee establishment. Pruning and handling to remove unnecessary branches, flowers and berries that compute to water/nutrients [23]. Terracing/contouring, application of effective irrigation, planting hedges, and contour planting to mitigate wind and water deficiency are important mechanism to withstand negative climate change impacts [22]. Building of biogas to remove methane gas which is the most potent greenhouse gas produced by fermentation in cow's stomach. Creating awareness about the impact of climate change to coffee producers and broadcasting daily weather information can help producers to avail and take measures for changing environment [31], [6].

5. Conclusion

Climate change is change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer [18]. It is the world's critical problem caused by the emission of greenhouse gases such as carbon dioxide (CO₂), nitrogen dioxide (N₂O) and methane (CH₄) which released to atmosphere and disturb Ozone layer. Deforestation for expansion of farming land also the other factor for climate change. The world's temperature is increasing resulting a huge loss to coffee (*arabica*) production both in yield and arable land for cultivation. High temperatures also known to disturb plant metabolism, coffee provoked leaf exposure to high irradiance and the absorption of much more energy than that usable by photosynthesis which intern the energy overcharge and to an overheating of leaves. Flooding, soil erosion, drought, prevalence of disease and quality reduction are some of many climate change negative impacts on coffee production.

Appropriate accomplishment of adaptation and mitigation strategies allow producer to withstand the climate change challenges. These activities are shade tree planting, drought resistance and environmentally adaptable variety development, cover crop planting, mulching, coffee-banana intercropping, irrigation, and rain water harvest. Conservation practices not only allow better growth of coffee tree within changing climate, but also improve soil structure and fertility. Planting shade trees enhance coffee cup quality and been size in addition to preventing high irradiant energy, strong wind and heavy rain fall. Comprehensive application of all adaptation practice ensure high quality and sustainable production of coffee and also maintain sustainable ecosystem.

6. Future Prospects

Coffee (*coffea arabica*) planting under shade is the most important for both quality improvement and maintaining sustainable production. In related with coffee leaf-rust disease severity and increment of carbon dioxide level in the atmosphere, the world's coffee (*coffea arabica*) production is shifting to under shade production. However, significant yield reduction was reported compared with coffee grown in open-sun. Hence, variety development for suitable shade tree

and determining the appropriate shade level is crucial.

Development of drought resistance, high yielding and disease resistance variety is a key task in order to have sustainable and quality coffee (*coffea arabica*) production although the molecular mechanisms underlying the adaptation of coffee plants to drought are largely unknown [32] due to its complex nature of genes to drought resistance trait. Further efforts and improvement activities on developing resistance variety are quite crucial to have sustainable and effective coffee production.

Further research on improved crop husbandry such as intercropping other than coffee-banana intercropping is also important. In Ethiopian context, coffee-enset intercropping has not been studied yet. The way the crops to be planted, the interaction effect and socio-economic values of the crops needs detail information, since, banana and enset are belongs to the same family (Musacea).

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