DOI: https://doi.org/10.20372/afnr.v1i1.630
Journal 0of Agriculture, Food and Natural Resources
J. Agric. Food Nat. Resour., Jun-Sep 2023,1(1):66-73
Journal Homepage: https://journals.wgu.edu.et

Review Article

Adaptation Strategies of Coffee Producers towards the Negative Impacts of Climate Change in Western Ethiopia: A Review

Amanuel Tilahun Etafa[1]*, Hika Wana Fufa[2], and Gadisse Dula Adugna[1]

[1]Department of Forestry, Wallaga University, P.O. Box 38, Shambu, Ethiopia

[2]Department of Agricultural Economics, Wallaga University, P.O. Box 38, Shambu, Ethiopia

Abstract

Coffee production is one of the most important agricultural sectors in the world including Ethiopia. However, climate change is the most adverse challenge of the 21st century. In terms of this, the inevitableness of the changing climate is progressively accepted by scientists and the public around the world. The effect of climate change and variability is adversely affecting coffee production in Ethiopia, particularly in the western part of the country. But, no or less study has been conducted concerning the issue of climate change adaptation strategies on coffee production and its implication for rural household food security. Therefore, this paper aims to review the effects of climate change on coffee production and livelihood in Western Ethiopia. The review result confirmed that coffee producers in western Ethiopia have been battling climate change impacts by implementing several adaptive strategies. Coffee shade management, irrigation of coffee farms, weeding and mulching, pruning of old aged and less productive coffee plants, and raising and planting seedlings of drought tolerant coffee ecotypes are some of the strategies that the coffee producers implemented to fight the negative impact of climate change on coffee production and productivity. Hence, to tackle the adverse effects of climate change and promote farmers' best practices, conserving the existing wild Arabica coffee genotypes and their evolutionary potential present in the country is critically important for maintaining coffee yield, pests and disease resistance, drought tolerant, quality and other important traits in the future coffee breeding program is crucial.

Article Information

Article History:
Received : 25-06- 2023
Revised : 04-07-2023
Accepted : 24-09-2023

Keywords:
Adaptation strategies
Climate change
Coffee producers
Livelihood

***Corresponding Author:**
E-mail:
amaanee97@gmail.com

INTRODUCTION

Climate change is any significant long-term change in the expected patterns of average weather of a region (or the whole Earth) over a significant period (Mahato, 2014). Climate change is unequivocal as there is now ample evidence that the earth's climate system is warming at an unprecedented rate leading to ice melting and sea-level rise (IPCC, 2014). Typically, this is a natural process that occurs through variations in the solar cycle (CFCC, 2017). However, since the 1800s, human activities have accelerated the process primarily by burning fossil fuels, such as oil, coal, and gas. The consequences include local and global temperature rise, severe fires, drought, flooding, melting polar ice, sea level rise, declining biodiversity, and catastrophic storms.

East Africa is experiencing rapid population growth, urbanization, and economic transformation. Despite rapid economic growth and urbanization over the last two decades, most of the region's poor live in rural areas and depend, directly or indirectly, on agriculture (CFCC, 2017). The impacts of climate change in East Africa were largely negative in terms of agricultural production, though there were significant variations in the scale of climate impacts across agroecological zones, farming systems, and livelihoods (IFPRI, 2004). Climate models predict that the Horn of Africa is likely to experience warmer temperatures, changes in the frequency and intensity of extreme events, decreased precipitation in the near term, and a rise in sea level in the long term.

Accordingly, the October to December 2020, March to May 2021, October to December 2021, and March to May 2022 seasons were all marred by below-average rainfall, leaving large swathes of Somalia, southern and south-eastern Ethiopia, and northern and eastern Kenya facing the most prolonged drought in recent history, while the March to May 2022 rainy season was the driest on record in the last 70 years (OCHA, 2022). The 2020 to

2022 droughts have now exceeded the horrific droughts in 2010 – 2011 and 2016 – 2017 in both duration and severity and will continue to deepen in the months ahead, with catastrophic consequences (OCHA, 2022).

The other drought special report also indicated that over 8.9 million livestock, which pastoralist families rely upon for sustenance and livelihoods have died across the region, including 3.5 million in Ethiopia, 2.4 million in Kenya, and over 3 million in Somalia (IFPRI, 2004).

Increased rainfall and temperature variability results in both droughts and heavy precipitation events, lowering agricultural production, including coffee production, with corresponding negative effects on food security (Marius, 2009). Due to climate change, the livelihood of coffee producers is highly affected as their production has shown a decreasing trend over time (IPCC, 2001). Destruction of natural coffee habitats consequently impacts coffee genetic resources and livelihoods (Sisay, 2018). The effects of these stresses on coffee production and livelihoods have already decreased exportable coffee production (Guido *et al*., 2018). Several qualitative studies have shown that while most farmers were aware of the effects of climate on their farming and livelihoods, they did not adopt these measures into their management practices (Chengappa *et al*., 2017; Harvey *et al*., 2018). According to the report of (CFCC, 2017), the climate of Africa, particularly Ethiopia, has changed dramatically and experienced a temperature increase of around 0.3°C per decade, and a reduction in rainfall since the 1950s.

In Ethiopia, climate change has resulted in numerous negative impacts on the agricultural sector and is predicted to have a variety of negative effects. Climate change has strongly harmed the sector, as the temperature increase and fluctuations in rainfall have been imposing difficulties, such as the prevalence of coffee pests and diseases, and damage to coffee plants (Iscaro, 2014). Coffee plants are highly susceptible to climate change. Thus, climate change hurt the agriculture of Ethiopia (Deressa, 2007).

Coffee is one of Ethiopia's most important foreign currency earners, and its production is the leading agricultural sector (USDA, 2018). In 2020, the Arabica coffee production was 584,790 tons (Bealu, 2021). Approximately 525,000 hectares of land in Ethiopia was covered by Arabica coffee (Moat *et al*., 2017; USDA, 2018). The country produced 456,000 tons of coffee in 2021(Knoema, 2021). Moreover, the smallholder coffee producers' livelihood is highly dependent on coffee production, processing, and marketing as they take the largest proportion of production with an average farm size between 0.5–2 hectares (Moat, *et al*., 2017; ICO, 2018; USDA, 2018).

Arabica coffee (the major type of coffee grown in Ethiopia) grows at approximately 18 – 21°C for optimum growth and taste (Davis *et al*., 2012). According to Davis *et al*. (2012), by 2080, the production of indigenous Arabica coffee will be reduced by 85 %. To withstand and mitigate the impact of climate change, it is vital to design and implement adaptation strategies suitable for the existing patterns of climate variability and agroecology in these areas. To achieve the objective of the review article, most importantly, recently published research articles and book chapters revealing the adaptation strategies conducted specifically in western Ethiopia were reviewed and synthesized. Thus, this paper aims to review the types of coffee production found in western Ethiopia, the effect of climate change on coffee production, the livelihoods of smallholder coffee producers, and the adaptation strategies to mitigate the negative impacts of climate change in western Ethiopia.

LITERATURE REVIEW

Coffee Production Systems in Ethiopia

In Ethiopia, the major coffee production areas are the western and southwestern regions as well as the southern, eastern, and central parts of the country (Tadesse, 2015). Coffee production systems are characterized according to the level of management, type of vegetation found in the system, structural complexity, and agronomic practices. Forest coffee, semi-managed forest coffee, garden coffee, and plantations are the four main production systems in Ethiopia. Smallholder farmers, who account for over 95 % of the coffee produced in the country, have practiced the first three production systems for centuries. Henceforth, they are collectively referred to as 'traditional' coffee production systems (Gole *et al*., 2002).

Forest coffee production systems involve gathering coffee found mostly naturally, and forest production, where coffee trees are simply protected and managed for convenient picking. In semi-forest coffee production systems, farmers slash weeds, lianas, competing shrubs, and thin forest trees and fill open spaces with local seedlings (Bealu, 2021).

In the garden coffee system, farmers gathered seedlings of shade trees, planted them around their homesteads, used the trees found around dwellings, and planted coffee under the shade of these trees. Fruit trees and other crops are grown in combination with coffee plants (Hika *et al*., 2023).

Garden coffee systems exist predominantly in the south (Sidamo), west (Wollega), and east (Harerge and Arsi). Very small-scale coffees growing in the marginal zones of northern Ethiopia such as Gojam and Wello can also be included in this category. Garden coffee accounts for approximately 50 % of national production (Woldetsadik and Kebede, 2000).

Commercial plantation coffee production systems were introduced approximately 100 years ago in the eastern part of the country, in the Gololcha district of the Arsi zone (Gole *et al*., 2002). This sector includes a few large private and state farms located mainly in the southwest and many smallholder plantations spread all over the coffee-growing areas. This type of coffee production system accounts for approximately 10 % of national production. Traditional production systems account for 90 – 95 % of production, while plantations may range from 5–10 % even though recent survey data are not available for an accurate figure (Tesfu, 2012).

Traditional production systems are mostly forest-based, and the differences between these systems are manifested in the intensity of forest management. Accordingly, the level of forest management ranges from little to no forest coffee to intensive management in home gardens and plantation systems (Björklund *et al*., 2012).

Coffee plantations are one of four different management systems. However, should keep in mind that these systems are

best thought of as a gradient from full-sun monoculture to highly shaded rustic polyculture (Osorio *et al*., 2002). In western Ethiopia, three coffee production systems have been identified and named as traditional methods: forest coffee, semi-managed forest coffee, and garden coffee (Aboma, 2016).

Other coffee production systems (growing coffee without shade) are not well known in these areas. However, there is a threat as the practice of coffee plantations without a shade of trees is expanding at an alarming rate to other parts of the country.

Growing coffee without shade was first introduced in the Gololcha District of Arsi Zone. Farmers are attracted to the system, believing that the yield of coffee from the system is relatively higher although it is unsustainable (Gole *et al*., 2002). Coffee grown under the trees is better because inorganic inputs for production are absent (Senbeta and Denich, 2006). Coffee plants grown under shade trees produced larger and heavier fruits with better bean quality than those grown in direct sunlight. Moreover, shade trees have biochemical cycling and physiological potential for high dry matter production, which would help them to maintain high coffee yields in the long term (Adugna and Struik, 2011).

Another research result by Amanuel (2022) stated that there was greater coffee yield, coffee weight, and coffee shrub density under the tree canopy than in open fields. Generally, coffee production parameters and coffee yield under the canopies of shade tree species and selected soil physicochemical properties showed relatively higher values than those without shade trees. Similarly, the study of (Amanuel *et al*., 2023) also detected that there was a greater yield of coffee under *Croton machrostachus* and *Cordia africana* than the coffee yield from the open areas.

Impacts of Climate Change on Coffee Production and the Livelihood of Smallholder Coffee Producer in Ethiopia

The report of the CFCC (2017) indicated that climate change has already hurt coffee production and, thereby, the livelihood of coffee producers. Additionally, dramatic forest loss has been observed in some coffee-growing areas.

Coffee plants are especially vulnerable to climate change because the higher humidity and warming temperatures are encouraging diseases and pests to thrive, and unpredictable temperatures and rainfall patterns are impacting harvest times and coffee quality (Getachew and Demelash, 2019). Thus, increasing temperatures and decreasing precipitation due to climate change will have long-lasting negative effects on Ethiopian agriculture (Deressa, 2007).

According to Jaramillo *et al.,* (2009), another main threat to coffee production in Ethiopia is insect infestation, which has radically increased in recent years, directly resulting from climate change. The insect known as the coffee berry borer, *Hypothenemus hampei*, is the largest pest of coffee plants. *H. hamper* is one of the few herbivores that can detoxify caffeine.

The livelihood of 85 percent of Ethiopia's population depends on agriculture. The agricultural sector constitutes approximately 40 percent of Ethiopia's gross domestic product (GDP). In this country, a diversified range of crops is under cultivation, while stimulants such as coffee, tea, and tobacco are the major cash crops (FAIRSCR, 2022).

Coffee production is a major economic activity in coffee-growing areas of Ethiopia. Therefore, smallholder coffee producers' livelihoods are highly dependent on coffee production, processing, and marketing (Bealu, 2021). The smallholder coffee producers take the largest portion of production as 90 % of coffee is produced by 2 million smallholders with an average farm size between 0.5-2 ha (Moat, *et al*., 2017; USDA, 2018; ICO, 2018).

Aboma (2016) stated that the main income sources of farmers in the Anfillo district of the Oromia region were coffee (70 %), non-coffee crops, mainly cereal crops (5 %), and coffee and non-coffee, including honey production (25 %). Additionally, coffee is an important cash crop in Sayo district, Kellem Wollega zone of Oromia region, and more than 50 % of the area's income is contributed by coffee and it is the major one in sustaining the life of most residents (Amanuel, 2022).

Ethiopian agriculture is prone to significant threats of shortage of rain because it depends on annual rainfall; therefore, droughts cause considerable damage and often lead to famine (Deressa, 2007). Biotic constraints, such as weeds, insects, and diseases, and abiotic constraints, including drought, low soil fertility, waterlogging, and low levels of technology throughout the nation, are other dangerous stresses to Ethiopia's agriculture (Deressa, 2007). Moreover, coffee berry borers and coffee leaf rust are becoming much more significant threats to coffee production than ever before (Iscaro, 2014).

In most parts of the coffee-growing areas of western Ethiopia, there is great economic reliance on coffee production (Hika *et al*., 2023). However, as the yield of coffee is reduced due to climate change, the price of coffee fluctuates and decreases, as a result the farmers are affected, and even their livelihood has become questioned. Farmers take money from the traders before they harvest coffee beans at the current price level and by the time, then after harvest the farmers take their coffee to the traders even if the price during harvesting time is greater than the price during the promised time. This trend is well known in western Oromia, and farmers are facing problems because they rely on coffee production. Most smallholder farmers do not have alternative income for survival (GAIN, 2019).

When there is timely rain onset with less fluctuation, the yield of coffee becomes progressive. Irrigation is confined to a few locations and mostly where water is easily available and can be diverted to the farm using simple means like diversion from rivers using trenches. Irrigation is mainly practiced in the east part of the Oromia Region in the Harar coffee zones. The use of chemical inputs, such as pesticides, fungicides, and artificial fertilizers is rarely practiced, and although certification is not common (Tefera, and Tefera, 2014). Ethiopian coffee can often be considered organic by default and may indeed exceed the standards set for organic certification. This shows that the coffee yield is more dependent on the availability of rain rather than the inputs incorporated into the system, in various coffee farm management activities that farmers conducted during some periods of production, the coffee plants were shown over-bearing and consequently, its quality became less (CFCC, 2017).

Adaptation strategies for the negative effects of climate change on coffee production

Shifting of coffee plantations to higher elevation areas

Different researchers argued that coffee plants must be transferred to areas with relatively higher elevations where temperatures are usually a few degrees cooler to minimize the effect of the increasing temperature (Jaramillo *et al*., 2011; Davis *et al*., 2012; Ramirez-Villegas *et al.,* 2012). Shifting coffee production to new areas seems crucial since the sequence of climate change is predicted to be severe in the future. However, planning for shifting coffee plants to higher altitudes requires critical attention to its feasibility. Hence, before deciding on the establishment of new coffee farms, the suitability of plantation areas must be confirmed in terms of climate, agroecology, possible land-use conflicts (e.g., land tenure) the market chain, and coordination (Campuzano *et al*., 2021).

Accordingly, there should have been attempts to shift coffee plantations to cooler areas in Ethiopia. For instance, coffee production is under practice in new areas of the country such as the Amhara Regional State. Thus, to ensure a resilient coffee sector in Ethiopia, migrating coffee plants to elevated areas is crucial. According to the CFCC (2017), the new areas predicted to be suitable for coffee relocation in Ethiopia are mostly found in the Southwest coffee zones, the South Rift Valley coffee areas, Southeast, and the North coffee zones.

However, Davis *et al.,* (2012) stated that re-colonizing Arabica coffee plants in Ethiopia is not necessarily a good idea for it takes many years for the plants to become productive again, which severely affects the coffee industry. Jaramillo *et al*., (2011) also confirmed that moving coffee plants to higher altitudes is difficult because Ethiopia does not have adequate high-altitude land for coffee farming. Moreover, they also revealed that Arabica coffee would need to move 167 m higher in elevation for every 1-degree Celsius increase.

Coffee production under the shade of trees

Retaining or preserving the existing shade trees or planting shade trees in coffee farms is based on the belief that it provides better conditions for coffee plants by reducing excessive light and mulching the under-tree soil with litter thereby improving both the soil's physical and chemical properties (Beer *et al*., 1998). Shade trees also reduce periodic over-bearing and subsequent dieback of coffee branches (Adugna and Struik, 2011). In addition to these benefits, shade tree species in a coffee farm provide fodder, timber, and other products to the livelihoods.

Coffee production under shade trees is an old practice and a traditional method in Ethiopia. In most coffee producing areas, farmers clear the understory of forest trees and plant coffee (Gole *et al*., 2002).

Further, the research result by Schroth *et al*. (2009); Vaast *et al*. (2016); and Rice (2018) stated that ecohydrological research in these shade coffee systems is becoming increasingly important since trees have been promoted as a strategy for mitigating and adapting to future climate. Vaast *et al*. (2016) and Rice (2018) also mentioned that shaded coffee plantations store more carbon than sun-grown coffee systems, thereby contributing to the reduction of greenhouse gases. In addition, the tree canopy provides some level of protection against the rising mean and maximum air temperatures (Baker and Haggar, 2007; Schroth *et al*., 2009; Vaast *et al*., 2016), which in recent modeling studies have been pointed out as the key climatic changes affecting coffee growth, yield, and quality (Schroth *et al*., 2009; Baca *et al*., 2014; Bunn *et al*., 2015). Jaramillo *et al*., (2011) stated that shade trees can cause a reduction in the temperature of up to 4°C. The shading of coffee trees should never be dense as this greatly reduces production. This entails adequate pruning and lopping to limit the growth of shade trees. In some respects, *Arabica coffee* appears to be better suited to cultivation under shade than *Coffee robusta* (Wintgens, 2004). Accordingly, to withstand the negative effect of climate change on Arabica coffee production, scientists have recommended that using shade trees in coffee farms is the best means to conserve coffee Arabica since shade trees intercept the coming solar light by their canopies and reduce its impact on the coffee plants (Amanuel, 2022).

Coffee and Shade Management

Coffee management is certainly related to shade tree management in which farmers undertake silvicultural operations like thinning of less vigorous and short-branched shrubs and trees, pruning, cutting off the side branches, and weeding of undergrowth, intercropping, and debarking. Moreover, coffee management involves the complete removal of the competing undergrowth, including the seedlings and saplings of the canopy trees on an annual basis, to increase coffee productivity (Aboma, 2016).

The pruning of shade trees within coffee production systems limits light and root competition between trees and crops. It is an important management practice and a means of obtaining fodder for animals and fuelwood for rural communities. It helps to achieve the desired plant shape and contributes to sustainable higher yields while contributing to disease and pest control (Bealu, 2021).

Coffee pruning is a well-known coffee management strategy undertaken in western Ethiopia. Older coffee plants were selected and cut at the knee (on average 75 cm-1m). The yield from aged coffee plants was lower. Thus, the main purpose of pruning coffee trees is to develop strong and manageable bushy type coffee trees for it allows the sprout of a young coffee generation with the full potential of bearing high and productive coffee berry (Wintgens, 2004). The farmers did not prune all aged trees at a time because of a reduction in the yield of coffee for some consecutive years after pruning until the pruned coffee plants became productive (Aboma, 2016).

Adoption of Robusta Coffee

Many researchers have revealed that ‘it is better to focus on the production of another type of coffee called Robusta coffee since miserable predictions of the future of coffee Arabica are increasing’ (CFCC, 2017). *Coffee canephora*, known as Robusta coffee, is a species of the Rubiaceae family, which originates in central and western sub-Saharan Africa. Robusta coffee is not cultivated in Ethiopia; however, there are many varieties in the wild that remain undiscovered (Campuzano *et al*., 2021).

Adoption needs pre-evaluation of the suitability of the agroecological conditions of the areas, and it requires introducing the coffee to farmers and then assessing the coffee producer’s

willingness to grow this new coffee type on their farms (CFCC, 2017).

Weeding and Mulching

Weeds are known to compete for resources such as water, nutrients, and sunlight. In coffee farms, weeds compete mainly for nutrients and moisture as they mostly cover the lower strata of the system. Weed reduces the yield of coffee if not removed indicating that it is vital to keep coffee farms weed-free (Aboma, 2016). Ideally, weeding should aim at limiting the growth of harmful vegetation and, as far as possible to permanently eliminate noxious vegetation, particularly grasses (Wintgens, 2004).

In many coffee farms in western Ethiopia, weeding has been undertaken once, twice, or more times depending on the growth stage of the coffee plants and the occurrence and abundance of weeds in the farms. For instance, in the Anfillo district (western Ethiopia), weeding is conducted more than three times for young seedlings of coffee plants under sparse shade trees (Aboma, 2016). Nevertheless, forest coffee, where there are dense and diverse populations of shade trees, is undertaken one or two times a year (Aboma, 2016). Moreover, most coffee growers in southwestern Ethiopia slash and dig through the weed twice in one cropping season (Demelash, 2018). Moreover, Asnake and Waldeamlak (2021) stated that weeding is performed twice on average within a year in Babo Gambel of West Ethiopia. In these areas, the two major weeding/slashing seasons are during the onset of the rainy season and at the beginning of the harvest season. This is because a few weeks after the onset of the main rainy season, most of the herbaceous vegetation grows and competes with coffee plants. Additionally, weeding is mandatory during harvesting for easy access and picking of coffee cherries from coffee plants and allows the collection of coffee cherries that mature early and drop onto the ground.

According to Aboma (2016) growing cover crops such as tree legumes (living mulch), under coffee trees can provide many benefits. Weeding/slashing provides a substantial volume of organic matter, which improves the physical condition of the soil under the coffee.

Another method to minimize the impact of climate change on coffee is the mulching of soil found underneath coffee plants. It increases the infiltration rate of the soil, improves soil moisture, and helps coffee farmers make their coffee production systems more resilient to climate variability. Mulching reduces the number of weeds on coffee farms and at the same time, dead or dried weeds are used as mulching materials (Aboma, 2016; Asnake and Waldeamlak, 2021). Mulching material can be generated from several sources, which include the by-products of coffee (hulls, parchment, etc.) and harvest residues such as corn and sorghum stover, bean and soya haulms also constitute excellent mulching material ((Wintgens, 2004).

Crop Diversification and Usage of Irrigation

Crop diversification is one of the best means and substitution solutions, as currently, existing coffee production areas will no longer remain conducive to coffee production. Introducing new coffee and associated crop varieties that are drought-resistant, and tolerant to extreme temperatures and pest and disease-tolerant is crucial to stabilizing the income of coffee farmers and other beneficiaries (CCACP, 2015). Introducing the advanced agroforestry practices combining diversified components like *Ensete* (false banana), plantation crops such as avocados, banana, citruses, mango, and other fruits, integrating of ground covers like zinger, cardamon, planting of trees as a windbreak, boundary planting and growing of the most suitable coffee shade trees and others in the coffee farms will enable the coffee sector resilient (Hika *et al*., 2023). Irrigating coffee farms with available water sources in coffee-producing areas is an important and decisive option (CCACP, 2015).

Indigenous knowledge of coffee farmers towards adaptation to climate change

Coffee farmers in Western Ethiopia use various adaptation strategies. For instance, as stated by Aboma (2016) and Ebisa (2014), farmers retain the trees in their coffee farms and manage the system by pruning, planting, and conserving tree seedlings, thinning less vigorous trees and shrubs, weeding, and mulching the underneath soils with the dried weeds. In the areas where water is available for irrigation, they have been making channels inter- and intra-rows of coffee plants and water their coffee plants (Aboma, 2016; Asnake and Waldeamlak, 2021).

Cultivation of ground covers, such as ginger and cardamom, is well practiced in most coffee-growing areas in the western and southwestern parts of Ethiopia. Crop diversification is an old practice in these areas. Farmers have been introducing fruit trees and trees with high commercial value, such as *Gravelia,* Cupressus, Eucalyptus species, and cash crops like Khat. Additionally, coffee producers have the tradition of pruning older coffee plants (Aboma, 2016; Asnake and Waldeamlak, 2021).

Summary

Coffee arabica is the predominant type of coffee produced in Ethiopia. It is a perennial woody shrub that is native the African mountain forests of Ethiopia. Coffee production systems in Ethiopia are considered traditional because they constitute 95% of the country's coffee production. Forest coffee, semi-managed forest coffee, garden coffee, and plantation coffee production systems are the four main production systems in Ethiopia. However, commercial plantation systems are absent in the western part of the country.

Many researchers have shown that Arabica coffee plants are highly vulnerable to climate change. Due to climate change, different researchers have predicted that by 2080, the yield of coffee will be reduced by 85% in areas where indigenous coffee Arabica plants grow naturally.

According to recent research reports, coffee producers have been combating the negative effects of climate change by using various adaptation strategies. Coffee management is a strategy that involves the complete removal of competing undergrowth, including the seedlings and saplings of canopy trees on an annual basis, to increase coffee productivity. Coffee pruning is a well-known coffee management strategy undertaken in western Ethiopia.

Weeding can be undertaken annually for two or more rounds depending on the growth stage of the coffee plants and the occurrence and abundance of weeds on the farms. Another

method used to minimize the impact of climate change on coffee is mulching of soil found underneath coffee plants. It increases the infiltration rate of the soil, improves soil moisture, and helps coffee farmers make their coffee production systems more resilient to climate variability.

Along with this synthetized review, the farmers of the study areas are well known for selecting suitable shade trees retaining the trees on their coffee farms, and managing the system for optimum coffee production and productivity. Crop diversification is one of the best means and substitution solutions, as currently, existing coffee production areas will no longer remain conducive to coffee production. Accordingly, farmers have been introducing fruit trees and trees with high commercial value, such as grevillea Robusta, Cupressus, and Eucalyptus species, and cash crops such as khat.

Various researchers have proposed that introducing *Coffee canephora* (*Coffee robusta*) into the study areas which are currently producing only Arabica coffee seems difficult for it takes more time until it becomes sufficiently productive. Adoption needs pre-evaluation of the suitability of the agroecological conditions of the areas, and it requires introducing the coffee to farmers and then assessing the coffee producers' willingness to grow this new coffee type on their farms. Regarding the introduction of *C. canephora*, there were no articles stating the adoption of this type of coffee in Ethiopia, particularly in the western part of the country.

Another way to reduce the impact of climate change is to shift coffee plants to relatively cooler areas. However, as different researchers confirmed, moving coffee plants to higher altitude areas is difficult and not applicable for Ethiopia does not have adequate high altitude areas.

This review identified the utmost adaptation strategies that coffee farmers in Ethiopia, tried to adopt particularly in the western parts of the country. The most adopted strategies are weeding, mulching enhanced coffee production under the shade of trees, and irrigation of coffee farms. The management of coffee and shade trees, and diversification of crops by using their indigenous knowledge of spatial and temporal arrangement of the components in coffee farms are also practiced widely.

In this regard, farmers should enhance the planting and conservation of shade tree species in coffee farms and other places. The government must consider coffee production under the shade of trees and other adaptation strategies towards climate change in agricultural policy-making and must promote and disseminate the best practices found in the western part into other coffee-producing regions of the country. Moreover, different non-governmental organizations working in these areas have to promote and support coffee production under the shade of trees and other suitable adaptation and mitigation strategies towards climate change in the context of Ethiopia. Generally, it is crucial to adapt locally most suitable strategies for the existing agroecology of coffee growing areas that are relatively easier to apply, and adaptation strategies that are socially, economically, and environmentally sound.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

FUNDING

No one funded this review

REFERENCES

Aboma, B. (2016). Ethnobotany of Shade Trees in Coffee Plantation System in Anfillo District, Kelem Wollega Zone, Western Ethiopia (Doctoral dissertation, Addis Ababa University), 21-23.

Adugna, D. B., & Struik, P. C. (2011). Effects of shade on growth, production and quality of coffee (Coffea arabica) in Ethiopia. *Journal of Horticulture and Forestry*, 3(11), 336-341.

Amanuel, T. (2022). Effect of dominant shade tree species on selected soil physicochemical properties and coffee production in Sayyo district, western Ethiopia. *Trees, Forests and People*, 8, 100245.

Amanuel, T., Gadisse, D., & Fantahun, D (2023). Soil physicochemical properties and coffee production under canopies of Croton machrostachyus and Cordia Africana tree species in Sayo district, western Ethiopia. *Agroforestry Systems*, 97(4), 519-531.

Asnake, A., & Woldeamlak, W. (2021). Effects of quality coffee production on smallholders' adaptation to climate change in Yirgacheffe, Southern Ethiopia. *International Journal of Climate Change Strategies and Management*, 13(4/5), 511-528.

Baca, M., Läderach, P., Haggar, J., Schroth, G., & Ovalle, O. (2014). An integrated framework for assessing vulnerability to climate change and developing adaptation strategies for coffee growing families in Mesoamerica. *PloS one*, 9(2), e88463.

Baker, P., & Haggar, J. (2007). Global Warming: the impact on global coffee. In SCAA conference handout. Long Beach, USA (Vol. 14).

Bealu, G.A. (2021). Review on coffee production and quality in Ethiopia. *Agriculture, Forestry and Fisheries*, 10(6), 208-2013.

Björklund, J., Araya, H., Edwards, S., Goncalves, A., Höök, K., Lundberg, J., & Medina, C. (2012). Ecosystem-based agriculture combining production and conservation—a viable way to feed the world in the long term? *Journal of Sustainable Agriculture*, 36(7), 824-855.

Bunn, C., Läderach, P., Ovalle Rivera, O., & Kirschke, D. (2015). A bitter cup: climate change profile of global production of Arabica and Robusta coffee. *Climatic change*, 129(1), 89-101.

Campuzano-Duque, L. F., Herrera, J. C., Ged, C., & Blair, M. W. (2021). Bases for the establishment of robusta coffee (*Coffea canephora*) as a new crop for Colombia. *Agronomy*, 11(12), 1-13.

CCACP (Climate Change Adaptation in Coffee Production). (2015). A step-by-step guide to supporting coffee farmers

in adapting to climate change. www.coffee and climate.org. Version January 2015.

CFCC (Coffee Farming and Climate Change in Ethiopia). (2017). Impacts, Forecasts, Resilience, and Opportunities Summary Report.

Chengappa P.G., Devika C.M., Rudragouda C.S. (2017). Climate variability and mitigation: Perceptions and strategies adopted by traditional coffee growers in India. *Clim. Dev.*, 9: 593–604.

Davis, A. P., Gole, T. W., Baena, S., & Moat, J. (2012). The impact of climate change on indigenous arabica coffee (Coffea arabica): predicting future trends and identifying priorities. *PloS one*, 7(11), e47981.

Demelash, T. (2018). Review of Coffee weed management in Southwest Ethiopia. *Journal of Biology, agriculture, and Healthcare*. ISSN 2225-093X (online), 8 (11):8-10.

Deressa, T. T. (2007). Measuring the Economic Impact of Climate Change on Ethiopian Agriculture: Ricardian Approach. World Bank Policy Research Working Paper No. 4342.

Ebisa, L. (2014). Effect of dominant shade trees on coffee production in Manasibu District, West Oromia, Ethiopia. *Science, Technology and Arts Research Journal*, 3(3), 18-22.

FAIRSCR (Food and Agricultural Import Regulations and Standards Country Report). (2022). United state Department of Agriculture, Foreign agricultural Service. October 28, 2022. Addis Ababa, Ethiopia

GAIN (Global Agricultural Information Network). (2019). Ethiopia Coffee annual report. GAIN Report Number: ET1904.

Getachew, W., & Demelash, T. (2019). The impact of climate change on coffee (*Coffea arabica* L.) production and genetic resources. *International Journal of Research*, 5(11), 26-34.

Gole, T. W., Denich, M., Teketay, D., & Vlek, P. L. (2002). Human impacts on the Coffea arabica genepool in Ethiopia and the need for its in-situ conservation. In Managing plant genetic diversity. Proceedings of an international conference, Kuala Lumpur, Malaysia, 12-16 June 2000 (pp. 237-247). Wallingford UK: CABI Publishing.

Guido Z., Finan T., Rhiney K., Madajewicz M., Rountree V., Johnson E., McCook G. (2018). The stresses and dynamics of smallholder coffee systems in Jamaica's Blue Mountains: A case for the potential role of climate services. *Climate Change* 147: 253–266.

Harvey C.A., Saborio-Rodríguez M., Martinez-Rodríguez M.R., Viguera B., Chain-Guadarrama A., Vignola R., Alpizar F. (2018). Climate change impacts and adaptation among smallholder farmers in Central America. *Agriculture and Food Security* 7, 57

Hika, W., Gezahagn, K., Amanuel, T., Fantahun, D., Nasir, A., Geleta, G., Bona, T., & Birhanu, Ch, (2023). Indigenous knowledge and traditional agroforestry practices and their implications for food security: the case of Wollega Zones, Western Ethiopia. *Geo Journal*, 88(3), 2787-2798.

ICO (International Coffee Organization). (2018). Trade Statistics Tables. International Coffee Organization.

IFPRI (International Food policy Research Institute). (2004). Ending hunger in Africa: Prospects for small farmers, Washington, D.C., USA

IPCC (International Panel on Climate Change). (2001). Climate Change 2001. Synthesis report. Cambridge University Press. Cambridge

IPCC (International Panel on Climate Change). (2014). Summary for policy makers in climate change 2014. Impacts, adaptation and vulnerability: contribution of working group II to the fifth assessment report. United Kingdom: Cambridge University Press

Iscaro, J. (2014). The impact of climate change on coffee production in Colombia and Ethiopia. *Global Majority E-Journal,* 5(1), 33-43.

Jaramillo, J., Chabi-Olaye, A., Kamonjo, C., Jaramillo, A., Vega, F. E., Poehling, H. M., & Borgemeister, C. (2009). Thermal tolerance of the coffee berry borer Hypothenemus hampei: predictions of climate change impact on a tropical insect pest. *PloS one*, 4(8), e6487.

Jaramillo, J., Muchugu, E., Vega, F. E., Davis, A., Borgemeister, C., & Chabi-Olaye, A. (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.

Mahato, A. (2014). Climate change and its impact on agriculture. International *Journal of Scientific and Research Publications*, 4(4), 1-6.

Marius, K. (2009). Climate Risks and Development Projects. Assessment Report for a Community-Level Project in Guduru, Oromia, Ethiopia. Bread for all, November 2009. P.9-11.

Moat, J., Williams, J., Baena, S., Wilkinson, T., Demissew, S., Challa, Z. K., ... & Davis, A. (2017). Coffee farming and climate change in Ethiopia: impacts, forecasts, resilience and opportunities-summary.

OCHA. (2022). Horn of Africa Drought: Regional Humanitarian Overview & Call to Action (Revised 21 September 2022).

Osorio, N. W., Alzate, J. M., & Ramirez, G. A. (2002). Coffee seedling growth as affected by mycorrhizal inoculation and organic amendment. *Communications in soil science and plant analysis*, 33(9-10), 1425-1434.

Ramirez-Villegas, J., Salazar, M., Jarvis, A., & Navarro-Racines, C. E. (2012). A way forward on adaptation to climate change in Colombian agriculture: perspectives towards 2050. *Climatic change*, 115, 611-628.

Rice, R. A. (2018). Coffee in the crosshairs of climate change: agroforestry as abatis. *Agroecology and Sustainable Food Systems,* 42(9), 1058-1076.

Schroth, G., Laderach, P., Dempewolf, J., Philpott, S., Haggar, J., Eakin, H., ... & Ramirez-Villegas, J. (2009). Towards a climate change adaptation strategy for coffee communities and ecosystems in the Sierra Madre de Chiapas, *Mexico. Mitigation and adaptation strategies for global change,* 14, 605-625.

Senbeta, F., & Denich, M. (2006). Effects of wild coffee management on species diversity in the Afromontane rainforests of Ethiopia. *Forest Ecology and Management*, 232(1-3), 68-74.

Sisay, B.T. (2018). Coffee Production and Climate Change in Ethiopia. In *Sustainable Agriculture Reviews 33*; Lichtfouse, E., Ed.; Springer: Cham, Switzerland pp. 99–113.

Tadesse, W. (2015). Coffee production systems in Ethiopia. Environment and Coffee Forest Forum, Addis Ababa, Ethiopia.

Tefera, A., & Tefera, T. (2014). GAIN Report (number ET1402–13/5/2014). USDA Foreign Agricultural Service. PP. 11.

Tesfu, K. (2012). Coffee quality and productivity as basic factors for sustainability in Ethiopia. 21st African Coffee Sustainability Forum United Nations Conference Center at Addis Ababa (UNCC-AA), Addis Ababa, Ethiopia.

USDA (United States Department of Agriculture). (2018). Ethiopia Coffee Annual. USDA Foreign Agricultural Service.

Vaast, P., Harmand, J. M., Rapidel, B., Jagoret, P., & Deheuvels, O. (2016). Coffee and cocoa production in agroforestry—a climate-smart agriculture model. Climate change and agriculture worldwide, 209-224.

Wintgens, J. N. (2004). Coffee: growing, processing, sustainable production. A guidebook for growers, processors, traders, and researchers. WILEY-VCH Verlag GmbH & Co. KGaA. Weinheim. PP.280-283

Woldetsadik, W., & Kebede K. (2000). Coffee production systems in Ethiopia. In: Proceedings of the workshop on control of Coffee Berry Disease (CBD) in Ethiopia held in Addis Ababa, 13–15 August 1999. Ethiopian Agricultural Research Organization, Addis Ababa, pp 99–106.