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Impact of climate change on coffee production: An overview

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Abstract
The impacts from climate change are already widespread and the consequences have been witnessed all around the world. India is among the countries most affected by climate change according to Global Climate Risk Index (2017) and in particular the southern states where coffee is grown. Coffee is the second largest traded commodity in the world next to petroleum products. The major producing countries are Brazil, Colombia, Vietnam, Indonesia, Mexico, India and Guatemala, whose economies earn considerable foreign exchange from the export of coffee. These countries are facing local and global impacts of climate change over the decades as any fluctuations in temperature, rainfall, humidity, soil nutrients, moisture, sunlight, aeration and soil temperature could impact the growth and productivity of coffee plants. Hence, adaption of mitigation strategies involving actions to reduce global warming is an important option to overcome the impact of climate variations on coffee production.

Keywords: Climate change, coffee berry disease, mitigation and temperature

Introduction
Climate change has become internationally recognized problem. Its impacts have been well acknowledged on global scale in a range of different sectors. Among the different sectors agriculture is being one of them. The impact of climate variations in all coffee producing countries is predicted to be negative and even though within a country it would vary a lot. Climate change is putting coffee production and their livelihood of coffee farmers and their families around the world at risk. But the world the world wide concern is the pace at which climate change is taking place and threats caused to the world flora and fauna diversity. If the changes are taking place at the present pace, many species are likely to become extinct due to their inability to adapt to the rapidly changing environment. Climate variability in terms of uncertain rain or delayed monsoon, flood, droughts and changing temperature will have measure impact on coffee production. Therefore, planning and implementing the mitigation and adaption strategies in a systematic manner would help to overcome the future challenges.
Coffee is the second largest traded commodity in the world next to petroleum products and is among the most valuable legally traded commodity from the developing world (FAO, 2014) [5]. The major producing countries are Brazil, Colombia, Vietnam, Indonesia, Mexico, India and Guatemala, whose economies earn considerable foreign exchange from the export of coffee. Across the world, more than 400 billion cups of coffee are consumed each year. More than 100 million people in the coffee growing areas worldwide derive their income directly or indirectly from the produce of this crop (Mishra and slater, 2012) [12]. Commercial coffee cultivation relies upon two coffee varieties; *Coffea arabica* (Arabica coffee) and *Coffea canephora* (Robusta coffee). Coffee production (over 90%) takes place in the developing countries while more than 75 per cent of it is consumed in developed countries (ICO, 2018). The total global production of coffee stood at 101.87 lakh tonnes and consumption at 97 lakh tonnes in 2018 (ICO). The coffee industry engages about 100 million people of which 20-25 million are small growers (Coffee Barometer, 2018) [3]. The reports of International Coffee organization details that coffee is supporting millions of small farmers and creates enormous employment opportunities in rural areas.

Table 1: Area, Production and Productivity of coffee in India

Coffee	Arabica	Robusta	Total
Area (ha)	202218	214523	416741
Production (MT)	95000	224500	319500
Productivity (kg/ha)	470	1047	767

Coffee cultivation in India is confined mostly to hilly tracts of Western and Eastern Ghats as a well distributed annual rainfall is preferable. In general, the area and production of coffee in India is about 4.16 lakh ha and 3.19 lakh MT, respectively with a productivity of 767 kg per ha (Table 1). Among total coffee area, arabica and robusta coffee was grown in an area of 2.01 lakh ha and 2.14 lakh ha, respectively with a production of 95 thousand tones (arabica) and 2.22 lakh MT (robusta). Coffee area is distributed in a total of 2, 91,000 holdings of which only 2,658 belongs to large grower sector in India (above 10 ha) (Database on coffee, coffee board of India, 2019) [7].

Table 2: Area and Production share of coffee in India by states

States	Arabica (%)	Robusta (%)	Total (%)
Karnataka	24	29.7	53.7
	21.3	47.4	68.7
Kerala	0.9	17.8	18.7
	0.7	21.4	22
Tamil Nadu	6.4	1.4	7.8
	4.1	1.4	5.6
NTA	18.3	0.1	18.4
	3.6	0.0	3.6
NER	1.4	0.5	1.9
	0.1	0.0	0.1

In India, coffee growing areas are classified into three different regions viz; Traditional regions, Non-traditional regions and North Eastern regions. Among three different coffee cultivating regions of India, traditional regions (Karnataka, Kerala and Tamil Nadu) contribute measure area share (80%) as well as production share of 96%. While the rest of the area and production share (20% and 4%, respectively) comes from Non-traditional region and North Eastern regions. Karnataka occupies maximum area share of 54% with a production share of 69% which include both Arabica (21%) and Robusta (47%) in India (Table 2).

Climate change and its causes

Climate change is a natural phenomenon and the biological system has its inherent capacity to adjust itself under changes happening in the external environmental conditions. According to Intergovernmental Panel on Climate Change (IPCC) report indicated that during the 21st century the global surface temperature is likely to rise a further 0.3 to 1.7 °C (0.5 to 3.1 °F) in a moderate scenario, or as much as 2.6 to 4.8 °C (4.7 to 8.6 °F) in an extreme scenario, depending on the rate of future greenhouse gas emissions (IPCC, 2019) [7].

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Causes of climate change can be divided into two categories, natural cause and human cause. Natural causes include Continental drift, Volcanoes, The earth's tilt and Ocean currents. While human made causes contribute more to the climate change.

Impact of climate change in major coffee producing nations

In many coffee producing countries like Brazil and Vietnam coffee is grown under open condition, without any shade coupled with intense cultivation practices aiming at higher productivity. The terrain of coffee areas in these countries is highly amenable for mechanization of farm operations which bring in efficiency. While in India, coffee has been grown under two tier shade in a more sustainable way for centuries. Coffee is cultivated in undulating terrains of varying gradations, which gives less chance for mechanization. Thus, indirectly coffee provides daily employment to the native inhabitants of hilly region.

Coffee has been introduced to India during 1600 AD and remained as a garden plant for nearly two centuries and later during 18th century commercial plantations were established. The plantations were raised in virgin jungles of the Western Ghats after selectively felling the undesirable trees by retaining desired number of jungle trees. Even when the Robusta, low land coffee was introduced into the 19th century, the importance of providing the natural shaded conditions was taken care. Thus the strong foundation was laid for sustainability of coffee industry and subsequently, India becomes the one of the few countries in the world to grow all of its coffee under natural shade canopy (Anonymous, 2014) [1].

In Brazil, Rising temperatures will reduce the overall acreage with climatic potential for coffee production. Production costs are likely to increase and water requirements may rise due to higher temperatures causing more evaporation, meaning many farmers may have to introduce irrigation in Colombia. The high-altitude regions where quality coffee is grown possibly would go to as high as 2,000 meter (Costa Rica). In India, reduced rainfall and higher temperatures are favoring the spread of pests as white stem borer and berry borer.

Why coffee is susceptible to climate change?

It is because of its environmental requirements. Arabica coffee evolved in the cool shady environment of the Ethiopian highlands, where there is a single dry season coinciding with winter months. The optimum temperature range is about 15 to 24 ^{o}C with a precipitation of 1500 to 2000 mm per year. Robusta is slightly hardier, as it evolved in lowland equatorial Africa, but grows well in areas with abundant rainfall of about 2500 mm per year. For robusta the rainfall should be well distributed as the plants are shallow rooted. The optimum temperature range for robusta is 24 to 30 ^{o}C, but it is less tolerant to very high or very low temperature. Climate disturbance have led to fluctuations in yield in almost all the coffee growing countries.

Twenty years of weather data parameters was recorded Rudragouda *at el.* (2017) [15] Central Coffee Research Institute (CCRI), Balehonnur, Chikkamagaluru (India) in order to compare the recent ten years data (2005-2014) with previous ten years data (1995-2004). The trend line analysis of rainfall data during the decade 2005-2014 indicated that the rainfall was increased by 65.43mm, 314.79mm and 30.46mm during summer, rainy and winter periods, respectively compared to last decade (1995-2004) and total rainfall increase was 410.68mm per annum (Fig. 1). Similarly, data from Fig. 2 had shown that the maximum temperature was increased by 0.8 ^{0}C, 0.5 ^{0}C and 1.0 ^{0}C during summer, rainy and winter periods, respectively compared to last decades (1995-2004) and average maximum temperature increase was 0.8 ^{0}C. Likewise, the minimum temperature also shown increased trend during summer (0.8 ^{0}C), rainy (0.9 ^{0}C) and winter (1.0 ^{0}C) period when compared to last decades (1995-2004) and total average minimum temperature increase was 0.9 ^{0}C (Fig 3).

Frank (2017) [6] conducted an experiment to investigate the perceived impacts of climate variability and the response actions, as well as the physical and socio-economic factors influencing adaptation to climate variability by smallholder coffee farmers. About 156 samples (Small holder farmers) were surveyed for different weather parameters viz; temperature, relative humidity, wind and drought. Results from the study indicated that, among the 156 small holder farmers, more than 80% of them were opined that all the weather parameters (temperature, rainfall, wind and drought) were increased moderately as well as significantly during the study year 2017 compared to the previous years. On other hand, smallholder farmers have varied perceptions about the impacts of climate change and variability on the weather elements. Over 68% of the smallholder coffee farmers perceived winds and droughts as having significantly increased, while 56% and over 84% perceived temperature and rainfall to have moderately increased in the last couple of years. While there was no change, reduced and significantly reduced weather parameters were opined by the rest (less than 20%) of the small holder farmers group.

Impact of climate change on coffee

Climate disturbance have led to fluctuation in yields in almost all the coffee growing countries. Global warming is expected to result in the actual shifts on where and how coffee would be produced. Dr. Peter Baker of CAB international is of the opinion that if there is a 3 ºC increase in temperature by the end of this century, the lower altitude limit for growing good quality Arabica coffee may go up by 15 feet per year. This may affect millions of producers as well as the all participants in the value chain of industry the end user, the coffee consumer. It is predicted that both arabica and robusta coffee growers would be affected. Raising temperature is expected to make some areas less suitable or completely unsuitable for coffee cultivation, incidence of pests and disease may increase and quality may suffer. Growers may have to depend more on irrigation, putting pressure on water resources. Overall the production cost is expected to become increase. Increase in temperature will force coffee to ripen faster than normal, impacting the inherent quality. Low grown arabica from tropical areas with higher temperatures mostly less quality in the cup compared to the same coffee grown at higher altitudes. The beans are softer and may well be larger but, lack the quality. Increase in temperature coupled with low rainfall or erratic distribution will affect flowering and fruit set. The International Coffee Organization (ICO) consider that it would be the most important; particularly considering the large number of small holder coffee farms whose capacity to implement means and methods to mitigate climate change affect may be low (Raghuramulu, 2019) [13].

Impact on coffee quality: Quality is an important parameter for any crop. Coffee quality is mainly assessed through the physical aspects of coffee beans such as bean colour, size, density and percentage of physical defects in producing countries, whereas cup quality is the main criterion in consuming countries. Numerous factors affect coffee quality, including soil water status, climatic conditions, maturity of coffee berries at harvest and bean processing (fermentation, washing, drying, storage, roasting and beverage preparation), agricultural management (shade, pruning, fertilization) and genetic properties of cultivars. The relationship between climatic parameters and agricultural production is a complex process given that the impact of environmental factors on crop growth and development varies according to the species, cultivar and phenological phases. Crop acclimation ability in a changing environment is determinant to its productivity, but the preservation of the quality is equally crucial to economic sustainability. In general, coffee quality is affected by two major factors such as temperature and rainfall.

One and half year old seedlings from *Coffea arabica* L. cv. Icatu grown in pots were transferred from a greenhouse into walk-in growth chambers and grown under controlled conditions until seedlings become 3.5 years old. Further, plants grown under 380/700 micro liter of CO_2 per liter of air were submitted to gradual raise in the temperature range from 25 ºC to 40 ºC for a period of four months. Fruits were harvested at 25 ºC, 30-35 ºC and 36-40 ºC and bean physical and chemical attributes with potential implications on quality were examined. Data indicated that mass of beans; density and yields were significantly affected by different temperature levels. While the plants grown under two different CO_2 concentrations had shown no significant difference with respect to bean yield and bean mass. However mass bean, density and yield were increased under higher CO_2 (700 mL CO_2 per lit of air) when compared to lower CO_2 (380 mL CO_2 per lit of air). On other hand, as the temperature increases the bean mass and yield decreases. It was surprising that, density shown reverse trend with varying levels of temperature, as the temperature increases the density of coffee bean also increases. Results from the study can be concluded that the super imposition of elevated air (CO_2) contributed to preserve bean quality by modifying and mitigating the heat impact on physical and chemical traits of coffee bean (Ramalho *et al.*, 2018) [14].

The study was conducted by Vaast *et al.* (2006) [18] to know the effect of light regime (45% shade or full sun) and fruit load (full (F), half (1/2) or quarter (1/4) of initial fruit load) on coffee production, branch leaf area, individual leaf area, leaf-to-fruit ratio and % of beans with larger sizes. The experiment was conducted for two production cycles during 1999 and 2000. Effect of different light regimes and varying levels of fruit load shown significant influence on all the parameters studied. Significantly highest yield of 2700 gm/plant and 1880 gm/plant was recorded under sun grown coffee compared to shade grown coffee during both years 1999 and 2000, respectively. However, shade grown coffee observed highest values for branch leaf area (730 and 590), individual leaf area (36 and 42), leaf-to-fruit ratio (18 and 18) and % of beans with larger sizes (63.5 and 72.1) during the year 1999 and 2000, respectively. On other hand, among the various levels of fruit load, full fruit load registered significantly highest (3463 gm/plant) yield compared to half (3210 gm/plant) and quarter (1698 gm/plant) fruit load during 1999. While, during 2000 the trend was reverse showing lowest yield of 928 gm/plant in full fruit load compared to half and quarter fruit load (1457 and 1889 gm/plant, respectively). The lowest yield under full fruit load during the subsequent year of 2000 clearly indicates the mechanism of alternate bearing in coffee plants. Similarly, percentage beans with lower size were also observed under full fruit load during 1999 (56.2) and 2000 (67.1). Whereas, half fruit load and quarter fruit load was recorded highest percentage with larger bean sizes during 1999 (61.7 and 67, respectively) and 2000 (70.7 and 71.8, respectively). The lowest percentage beans with larger size under full fruit load might be due to competition among the fruits for carbohydrates resulted in smaller bean size. Form the study it can be concluded that shade decreased the production of coffee but improved bean quality (percentage beans with larger size) and fruit thinning is an important operation which prevents alternate bearing in coffee plants with improved bean characteristics.

All the biochemical composition of coffee beans was significantly influenced by different light regimes (45% shade or full sun). Whereas, varying levels of fruit loads and interaction study shown no significant difference for all the coffee bean biochemical composition during both the years (1999 and 2000). Results indicated that among the different light regimes, shade grown coffee recorded significantly highest caffeine (14.8 and 14.1g/kg) and fat (132 and 117 g/kg) content during 1999 and 2000, respectively. Whereas, highest sucrose of 84 and 78.4, chlorogenic acid of 77.1 and 82.6 and trigonellin content of 10.7 and 10.1 was recorded during 1999 and 2000, respectively. The highest values of sucrose, chlorogenic acid and trigonellin content under sun grown coffee might be due to incomplete maturation of coffee beans under sun grown coffee explains higher bitterness and astringency. Sucrose is a precursor of polysaccharides and fat compounds in coffee beans. Therefore high sucrose content coupled with low fat under sun grown coffee could very well indicate that bean filling and fat synthesis were not full achieved (Vaast *et al*., 2006) [18].

The effect of tree productivity manipulated by fruit thinning and light regime on the size and biochemical composition of coffee beans and their impact on beverage quality studied by Vaast *et al.* (2006) [18] shown significant influence with respect to all the parameters. Among the different cup quality parameters, maximum acidity of 2.27 during 1999 and 2.45 during 2000 was recorded under shade grown coffee. In addition, more preference values was also recorded highest under shade grown coffee during 1999 (2.57) and 2000 (2.80). Whereas, highest values of bitterness, astringency and body during 1999 (2.95, 1.86 and 2.91, respectively) and 2000 (2.88, 0.41 and 2.67, respectively) were observed under sun grown coffee. This is might be due to incomplete maturation of coffee beans under sun grown coffee explains higher bitterness and astringency.

Impact on running blossom

The unpredictable rains or uncertain rains will make the coffee plants to flower at various times throughout the year this phenomenon is known as running blossom or off season flowering or continuous flowering in coffee. Rainfall or early irrigation (before the full maturation of flower buds) can lead to floral abnormalities and running blossom which results in poor fruit set. Which ultimately making the farmers to harvest small quantities continuously this will affect the physiology of coffee crop.

Silva and Muzzafera (2017) [16] reviewed the influence of temperature and water on coffee culture with an objective was to know the effect of water deficit on flowering synchronization and fruit maturation. During the study the plants were subjected to different irrigation treatments viz; non-irrigation, continuous irrigation, withholding irrigation for 30 days during July and withholding irrigation for 60 days during July and August. Results revealed that withholding irrigation for 60 days during July and August increased leaf water to reach its potential of -1.1 to -1.6 MPa resulted uniform flowering synchronization as well allowing fruit to mature uniformly.

On other hand, the higher number of flowering buds with low uniformity in the fruit maturation was observed in the plants supplied with continuous irrigation. These results clearly indicated that drought or period of moisture stress is must for coffee flower buds to mature completely and initiate uniform flowering in coffee plants.

Impact on growth and yield (physiology)

Coffee bushes are highly sensitive to change in the adverse climatic conditions such as increased temperature, unpredicted rainfall; heavy wind and droughts affect the physiology of coffee plants. Like every crop coffee requires optimal weather conditions for its better performance in the form of growth and development.

Study conducted by Rudragouda *et al.* (2017) [15] on climate change in coffee tracts of Western Ghats of India at Central Coffee Research Institute (CCRI), Balehonnur (India) with an objective was to assess the changes in weather pattern particularly on temperature and rainfall and its influence on growth and development. Study on physiological and microclimatic conditions on Sln. 795 and Sln. 12 under different shade patterns indicated that adverse influence of silver oak monoshade on photosynthetic parameters and microclimatic conditions on both Sln. 795 and Sln. 12 cultivars even at adequate moisture conditions. Significantly highest net photosynthesis (Pn) was recorded under multiple shades of Jack, Ficus, Avocado and Erythrina trees in both Sln. 795 (66.02%) and Sln. 12 (45.23%) coffee cultivars which was associated with reduced transpiration rate (E), vapour pressure deficit (VPD), leaf temperature (Tleaf), photosynthetic active radiations (PAR) and higher relative humidity (RH%). Whereas the cultivars under monoshade exhibited lower Pn due to higher E, VPD, less Tleaf, PAR and low RH% had shown adverse influence of silver oak monoshade on coffee plants. Therefore results from the study can be concluded that multiple shade trees improved the growth as well physiology of coffee plants by preventing plants form adverse climatic conditions.

Chengappa and Devika (2016) [2] conducted an exploratory study on climate variability concerns for the future of coffee in India at Kodagu coffee growing region. The objective of the study was to analyse the variability of selected climatic factors in a predominantly coffee growing region on yield (Arabica and Robusta). The yield data indicates a continuous fall in Arabica mainly attributed to increased infestation of white stem borer. While the Robusta that is not susceptible to this pest shows a steady increase in yields in the district. If viewed decade-wise, there was a sharp rise in yield from 1980 to 1989, however, the yield decreased considerably in later years leading to low growth in production. The growth rates for production and yield for coffee in Kodagu stood at 3.52 per cent and 0.5 per cent respectively in the recent decade. From the study coffee growers opined that the microclimate in their farms was affected when the temperature, relative humidity and solar radiation fluctuations increased significantly as shade cover decreased. The farmers explicitly pointed out that uneven distribution in rainfall and increasing day time temperature in the last 10 to 20 years affecting the biological processes resulting in low yields and high incidence of pest and diseases such as white stem borer (Prabhu, 2014).

Impact on pests

Thermal tolerance of the coffee berry borer (CBB) *hypothenemus hampei*: predictions of climate change impact on a tropical insect pest was studied by Jaramillo *et al.* (2006) with an objectives was to determine the thermal tolerance of the coffee berry borer, *Hypothenemus hampei*. The inference was made on the possible effects of climate change using climatic data from Colombia, Kenya, Tanzania and Ethiopia. Analysis of 32 years of climatic data from Jimma (Ethiopia) revealed that before 1984 it was too cold for *H. hampei* could able to complete not even one generation per year, but thereafter, because of prevailing of warmer conditions the CBB could able to complete 1 to 2 generations per year/season. Calculated data on warming tolerance and thermal safety margins of *H. hampei* for the three East African locations showed considerably high variability compared to the Colombian site. On other hand, the number of generations of CBB in Ethiopia was found to be lowest due to the existence cooler climatic conditions. In Kenya and Colombia, the number of pest generations per year was considerably and positively correlated with the warming tolerance.

The effect of eight temperature regimes (15, 20, 23, 25, 27, 30, 33 and 35 ºC) on the bionomics of *H. hampei* was studied. Successful egg to adult development occurred between 20 to 30 ºC. Using linear regression and a modified Logan model, the lower and upper thresholds for development were estimated at 14.9 and 32 ºC, respectively. However, the CBB development was affected at more than 30 ºC. Results from the study can be concluded that CBB can survive and reproduce within a broad temperature regime and that the potential number of generations as an indicator of the pest status varies profoundly with daily seasonal temperature. Therefore the shade is the ultimate control which refuse the insect arthropods and leading to high level of biological control (Jaramillo *et al.*, 2006).

Liebig *et al*. (2018) [10] was conducted an experiment for two successive years during 2014-15 and 2015-16 to study the seasonal development of coffee white stem borer. The data showed that the average number of CWSB new entry holes were highest during the month of December for both the year (2014-15 and 2015-16). There were more attacks in the second rainy season (October/November 2015/2016) than in the first rainy season (March/April 2015/2016). A higher infestation during the month of December might result in less time spent on pest management at second onset of monsoon during the month of October. Therefore control measures might be focused on the start of the two rainy seasons as the rainfall patterns synchrony with emergence of CWSB adults.

Clusters based on hierarchical classification showing cluster means for input variables was studied to analyse the incidence of CWSB under two different variables such as shade tree density and varying levels of altitude. In this study, Liebig *et al*. (2018) [10] was carried out cluster analysis and developed five clusters to correlate the incidence of CWSB under different shade tree ecosystem and altitude range. Results revealed that, among the five different cluster classifications, cluster V and IV was recorded significantly higher CWSB incidence of 46 and 45%, respectively than cluster I, II and III. However, it was surprising that the lower incidence of CWSB was observed under cluster I, despite of having high density of shade tree. These results can be concluded that higher incidence of CWSB under more shade tree cover might be due to African CWSB prefers more shaded conditions in order to regulate its body temperature. Shade also increased minimum temperature appear to enable CWSB establishment. This could be important for adult during reproductive and oviposition phase as well as early instars larva.

Impact on diseases

Thirty randomly selected trees were taken to assess the relationship between altitude and coffee leaf rust (CLR) and coffee berry disease (CBD) incidence on coffee farms sampled in the Arabica coffee growing regions of Uganda. Results revealed that CLR disease incidence was negatively correlated with altitude i.e. as the altitude increases the incidence of CLR increases. On other hand, the CBD had shown positive correlation with altitude i.e. as the altitude increases the CBD disease incidence increases. Results from the findings can be concluded that temperature and moisture conditions vary as the altitude increases. This subsequently translates into successful spore germination and colonization of CLR and CBD at different altitudes (Matovu *et al*., 2013) [11].

Incidence and severity of CLR and CBD as influenced by shade intensity in coffee fields sampled in the Arabica coffee growing regions of Uganda was studied by Matovu *et al*. (2013) [11]. Different shade tree intensity viz; no shade, thin shade, medium shade and thick shade were evaluated for two different diseases (CLR and CBD). Significantly highest incidence of CLR and CBD was observed under thin shade (71.4% and 4.1%, respectively) was on par with medium shade (61.9% and 2.1%, respectively) over the other two shade tree intensity. Similarly, the highest percent of disease severity CLR disease was also noticed under thin shade (2.0%) which was on par with medium shade (1.9%). These results might be due to optimum microclimatic conditions that favour the CLR and CBD diseases due to efficient light penetration under such conditions keeps temperature well regulated. Further, open farms possess lower humidity results spore germination might have failed to penetrate the host plant.

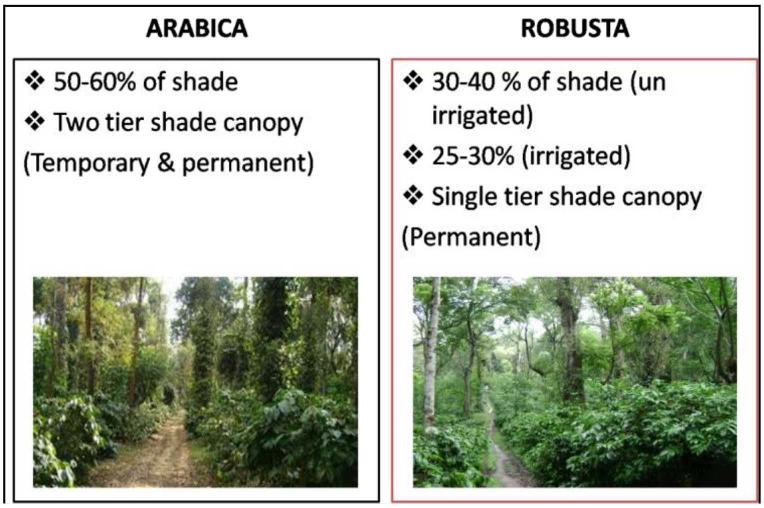
Kodagu disaster - A natural cause on coffee plantation

Heavy rain had damaged entire Kodagu district in all the departments which cause huge socio-economic damage to the whole district. During the cause many people lost their houses, lands and valuable coffee plantations. At this junction, the Coffee Board of India had taken quick crop loss survey on coffee due to flood caused by heavy rain during the year 2018. The survey was carried out by Coffee Board of India in collaboration with state horticulture, agriculture and revenue department of Karnataka (India). All the departments together started coffee crop survey in two major coffee growing belts of Kodagu district (Madikeri and Veerajpet). Survey results indicated that the total of about 21,000 hectare coffee area was surveyed from these two major talukas (Madikeri and Veerajpet) and reported more than 70% of the coffee crop loss due to floods, landslides, premature berry drop and severe defoliation caused by heavy rain. All the coffee area surveyed (21,000 ha) was declared for the crop loss compensation. The compensation of Rs. 38,000 per hectare was distributed to all the beneficiaries (coffee farmers) by Natural Disaster and Resource Management Fund (NDRF).

Mitigation strategies

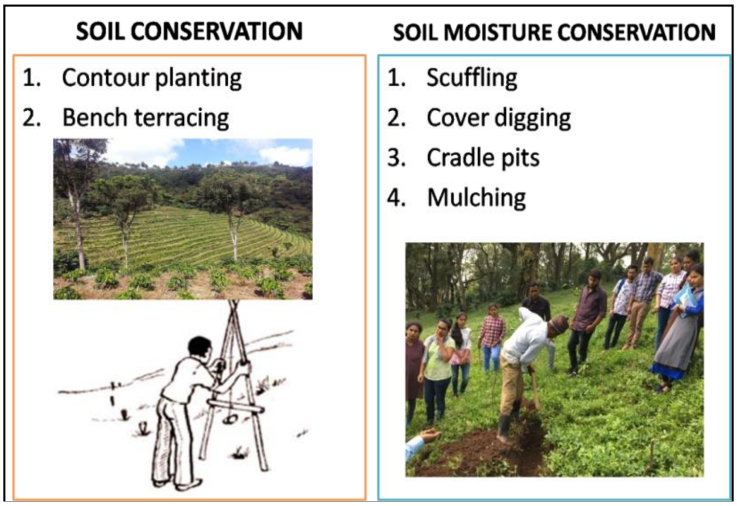
1. Shading of coffee plantations: The high diurnal variations in temperature, high light intensities and pronounced dry and wet spells, characteristics to coffee growing areas in South India make it mandatory to grow coffee under shade. It is recommended to provide a two tier mixed shade canopy comprising of lower tier temporary shade trees and top comprising of permanent shade trees of native species.

Besides growing suitable intercrops like Pepper, Orange, Banana etc., would also contribute to the shade, soil fertility and improved microclimate in coffee plantations. Shade also acts as a sort of insurance against vagaries of weather and market fluctuations. Considering the significance of shade in coffee plantations, the CAFNET team in India has studied how the change in tree cover from predominantly native tree species to exotic species (mainly silver oak) is affecting the water dynamics in the coffee agroforestry systems in the Cauvery watershed of Kodagu district, the most important coffee district of the region. During 2 years (2008-2010), six sites were selected in terms of rainfall regime along with West-East transect (Deciduous Western Zone: 40-70 inches/year, Central Zone: 70-110 inches/year) in the Cauvery watershed, the central watershed of the Kodagu district. In each site, two adjacent plots (less than 200 m apart) were selected, one predominantly composed of native shade tree species and another with predominantly composed of silver oak, the main exotic species. Study indicated that the amount of rain infiltrating into the soil is greater in plots having native tree species of shade trees than in plots having exotic shade tree especially in the Western and Central zones where there is a lot of rainfall. Results also showed that coffee under shade of native trees transpires more than coffee under exotic shade trees (mainly silver oak) during all the seasons but particulary during dry period, because of the plants under native shade trees are less water stressed, especially during the middle and of the dry season than the coffee under shade of silver oak (Kushalappa and Raghuramulu, 2005).



Shading of coffee plantations

2. High Density Planting and pruning systems: Arabica coffee produces finest quality coffee compare to robusta. But the productivity of arabica coffee is less (470 kg/ha) compared to robusta coffee (1047 kg/ha) (Database on coffee, coffee board of India, 2019) [4]. Therefore farmers are replacing arabica coffee with robusta coffee in order to increase their farm productivity. Hence, area under arabica coffee is decreasing drastically while area under robusta coffee is increasing. In addition, increase in area under robusta creates wider area of lower shade trees. This brings major changes in ecosystem (increase in temperature and change in rainfall pattern). Therefore it is necessary to promote as well as increase arabica productivity by adopting suitable agronomic practices such as high density planting systems to bring the balance in coffee ecosystem.



Soil & moisture conservations

3. Soil moisture conservation: The undulating terrain and heavy monsoon rain in coffee areas make it mandatory to adopt soil erosion preventive measures. Of course the two tier shade canopy is the first component of soil conservation measures. Shade tree reduces the velocity of rain drops and help in percolation of rain water into deeper layers. Contour planting, terracing and staggered planting/trenching across the slope are the other practices to be adopted in coffee plantations. Although the coffee tracts receive heavy rainfall of 2500-3000 mm rain per annum, the areas experience a dry period of 3-6 months from November to March/April. Thus, the lack of adequate moisture in soil becomes a limiting factor for growth of coffee during dry periods, which makes it mandatory to conserve the soil moisture *in situ*. A number of soil conservation measures like post monsoon scuffling, mulching young coffee, cover digging, opening of cradle pits across the slope (staggered trenching) in established holdings are commonly recommended. Theses trenches acts as mini compost pit inside the coffee plantation (Anonymous, 2014) [1].

4. Drought amelioration: In adequate and uneven distribution of rainfall causes drought conditions in coffee, which effects vegetative growth, induce floral abnormalities results in poor fruit set and prolonged drought increases production of more pea berries and "B" grade beans and ultimately loss in crop yield. Plants very in their capacity to tolerate drought depending on their genetic constitution. High 'osmotic adjustments' occur in the drought-tolerant cultivars through accumulation of solutes such as proline, nitrogen, phosphorous, potassium and calcium etc. these compounds increase the bound water capacity, regulate the stomatal movement, trigger water uptake, induce heat stability and maintain the integrity of membrane. In order to combat the drought, it is recommended to adopt drought ameliorative spray like nutrient mixture spray, Lantana camera extract spray or contact shade management using lime solution or planting drought tolerant selections in new areas (Anonymous, 2014) [1].

5. Nutrient mixture spray: Attempts have been made to overcome the impact of drought in robusta coffee through osmotic adjustment. Foliar application of nutrient mixture viz; Urea (1 kg) + SSP (1 kg) + MOP (0.75 kg) + $ZnSO_4$ (1 kg) dissolved in 200 liter of water applied on the coffee bushes at the rate of one liter per plant. The application of nutrient mixture spray has to be done in two stages; the first spray should be carried out 45 days after the last rainfall and second must be given 45 days after the first spray will mitigate the effect of drought. Alternatively, foliar application of *Lantana camera* leaf extract at 1% twice at monthly intervals during second fortnight of January and February could be taken up.

Lime spray as a reflectant: Foliar spray of 10% spray lime ($Ca(OH)_2$) in combination with 0.5% starch (20 kg spray lime along with 1 kg starch in 200 l of water) could be given to the upper surface of the leaves, once after 40 to 45 days of last rainfall. The lime spray reflects the direct solar radiation thus, reducing leaf temperature and acts as a contact shade protecting the leaves from chlorosis and scorching.

Planting drought tolerant selections: Studies conducted by CCRI had proved that among arabica selections, Sln. 9 and Sln. 5B are relatively tolerant to drought. Wherever new planting or replanting is being taken up it is suggested to plant such drought tolerant coffee selections.

Nutrient spray for young clearings: Foliar spray of nutrient mixture at half dose of field plants (Urea 0.5 kg + SSP 0.5 kg + MOP 375 g + $ZnSO_4$ 0.5 kg) will protect the young coffee from adverse effects of drought. Foliar spray of *Lantana camera* leaf extract at 1% twice during the second fortnight of January and February (a month apart) boosts the growth of young coffee and protects from the adverse effects of drought.

6. Need based irrigation: Coffee is primarily cultivated as a rainfed crop worldwide. In equatorial regions such as South and Central America, where there are no well defined alternations between wet and dry periods, coffee is generally not irrigated. But in the regions of single rainfall regime such as East and Central Africa and India, coffee is irrigated during the 4 to 6 month dry spell. This substantially boosts growth and productivity. Coffee, being an evergreen plant, requires maintenance of soil moisture during dry months. In the coffee tracts of South India, the South-West monsoon provides more than 60% of the rain during June to September and the rest is during the North-East monsoon period in October to December. The dry period usually consists of 4 months from December onwards. In some years the North-East monsoon tapers off by the end of October itself leading to an extension of the dry period. The most important factor which limits the production of coffee even in well managed estates is the long dry period. Besides this, if blossom rains are delayed beyond March then the production of coffee receives a major setback. In coffee, irrigation is mainly used as an insurance against failure of good blossom and backing showers and for overcoming long dry period. Hence, farm pond can be dug or small check dams can be constructed across hillocks to conserve the water. This water can be used for providing irrigation during summer months. Robusta coffee being susceptible to drought, responds well to irrigation compared to arabica. First winter irrigation must commence 20 to 25 days after the cessation of monsoon. Irrigation up to 25 mm once in 20 to 25 days till the end of December is a must. Later blossom irrigation at 25 to 38 mm is to be given during the second fortnight of February followed by backing irrigation with a gap of 15 to 20 days after blossom. Just blossom and backing irrigation improved yields by 48 to 57% and continuous irrigation throughout dry period gave a yield increase of 85 to 95% over un-irrigated plots in robusta coffee.

Establishment of young coffee is much better with drip irrigation compared to sprinkler irrigation as there is less weed growth. Application of 3 to 4 l of water once a week was found to be ideal for establishment of young coffee. In established plantations, application of 8 l of water per plant on alternate days to Cauvery and daily to robusta during dry months from November to May could increase the crop yield by 28% and 48% respectively. Drip irrigation in arabica (Cauvery) coffee allowed for natural blossom showers while in robusta, blossom could be induced by applying around 200 l of water per plant during February-March through drippers or micro-sprinklers. This blossom irrigation needs to be given at a stretch, after withholding daily drip irrigation for about 15 days prior to blossom irrigation.

7. Nutrient management: Coffee being a perennial crop, the plant has the dual function of maturing the crop and producing fresh cropping wood frame work for the succeeding year simultaneously. In coffee cultivation, nitrogen, phosphorus and potassium are considered as major nutrients; calcium, magnesium and sulphur as secondary nutrients, while iron, manganese, copper, zinc, molybdenum, boron, sodium and chlorine as micro-nutrients. All the essential nutrient elements supplied in adequate quantities to sustain the growth and yield of the plant is called balanced fertilization. Restrictions on coffee production due to soil nutrient deficiencies are removed by applying appropriate fertilizers in right time and quantities. The most economic quantities of nitrogen, phosphorus and potassium required to be supplied to a given block depends on the estimated yield, performance of plants for the last three or five seasons and the soil test data. Doses of nutrients applied without considering the soil test values will be inaccurate, uneconomic and incomplete.

To meet the nutrient requirements, the following practices should be followed. Green manure crops like *Crotolaria* sp. and legumes like cow pea, horse gram could be cultivated for 2 to 3 years to build up soil fertility. The coffee wastes that are available in the plantation should be recycled effectively through aerobic/heap method of composting. Compost should be applied at the rate of 2.5 tonnes per hectare per year in two splits. The soil pH should be corrected using agricultural lime or dolomite based on the soil test results. A deficiency of nutrient supply should be met out by application of rock phosphate, bone meal, wood ash and other permitted products. In addition to this leaf litter biomass from shade trees contributes about 10 MT/ha/year which adds additional nutrient of about 40-60 kg N, 30-33 kg P_2O_5 and 40-60 kg K_2O to the soil. Processing byproducts pulp or husk for every tonne of clean coffee produced on the farm with a nutrient value of 14-15kg N, 3-3.7 kg P_2O_5 and 29-37 kg K_2O is enough to support a crop of about 500 kg/ha.

8. Pests and diseases management: Maintenance of multiple shade system instead of mono shade with silver oak will decrease white stem borer as multiple shade with forest trees will provide cool micro-climate which is unfavourable to stem borer. Providing mulch of natural shade trees helps in suppression of harmful pests and diseases. A healthy soil with optimal physical, chemical and biological properties increases the plant resistance to pests and diseases. Regular soil testing and application of organic manures helps in building of carbon in soil and plant health.

9. Diversification in coffee: Mixed cropping also referred to as inter cropping, multi-storied cropping, diversification etc., means cultivation of two or more compatible crops for better utilization of available land and resources to the best advantage of growers. The risk involved in depending on a single crop or mono culture is always greater than an investment in an assortment of crops.

Coffee in India is grown as a silvi-horticulture crop under a tree cover for optimal performance. This situation paves way for bringing about an association of several economic species together. The shade grown conditions in coffee holdings are ideal for cultivation of many fruit and cash crops and spices. Besides, the typical characteristic of small, fragmented holdings in hilly areas, which are not amenable for intensive cultivation, also necessitated the need for growing multiple crops in coffee holdings. Moreover, the soil and climatic conditions prevailing in the coffee areas, especially in the Western Ghats are ideally suited for a wide variety of fruit and spice crops. Here the strategy has been to grow compatible crops that have varying canopy and root structures in a manner that their canopies intercept sunlight at varying heights and their roots tap moisture and nutrients from different depths of soil without interfering with the growth of coffee.

In this diversification farm, two major experiments were initiated to study the feasibility and economics of cultivating different crops (mixed cropping) with coffee. The first experiment was on diversification of coffee with already known associate crops like mandarin, orange, black pepper and banana with both Arabica and Robusta either grown individually or in combination with other crops. In the second experiment, the multi-storied cropping pattern combined with strip planting was adopted so that the coffee, shade trees and associate crops were grown in organized strips to facilitate individual management of coffee and other crops and to reduce competition/ interference among various crops. In both these experiments, various annual/short term crops including ginger, turmeric, pineapple, banana, papaya, cotton, and vegetables were cultivated with the objective of studying their suitability in young coffee and to realise some supplementary income during the pre-bearing stage of coffee. Apart from initiating field experiments on diversification in coffee, the planting material of orange, black pepper, banana, arecanut, pine apple etc., were supplied to small coffee holdings free of cost to encourage mixed cropping.

The results on diversification indicated that during the initial three years of planting coffee, an income of 15,000/- per ha was obtained including coffee and other annual/short duration crops. Over a period of 14 years of experimentation, it was well established that black pepper is the most suitable mixed crop in both Arabica and Robusta coffee with a cost-benefit ratio of 1:3.1 and 1:2.29 respectively in Arabica + pepper and Robusta + pepper combinations. Orange was found to be compatible only with Arabica coffee with a cost-benefit ratio of 1:1.86. Arabica was found to be compatible with a combination of pepper, orange and banana with a cost: benefit ratio of 1:2.20 while in case of Robusta the same combination was found to bring down the cost benefit ratio to 1:1.32 indicating the suppression effect of too many intercrops on Robusta performance.

Conclusion

Global warming is predicted that rising temperatures and water shortages will negatively affect coffee production suitability at lower elevations and vice versa. The already perceived impacts of climate change on coffee production will not only be threat small scale farmers but also all actors involved in coffee industry. Therefore, it is possible to withstand the negative impacts of climate change by different adaptation and mitigation practices viz, shade use and reforestation, crop improvement, intercropping and other conservation practices. Comprehensive accomplishment of these practices helps to alleviate the impact of climate change on coffee.

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