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Research Article

CLIMATE CHANGE IN COFFEE TRACTS OF WESTERN GHATS OF INDIA

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Abstract- The coffee plant is a woody perennial dicotyledon of the genus Coffea (Rubiaceae) consisting of over 80 species, out of which only two species are important for production of coffee beans – Arabica (*Coffea arabica*) and Robusta (*Coffea canephora*). Coffee cultivation provides livelihood for nearly 1.5 million families. Coffee has proven to be highly sensitive to climate change. Temperature and rainfall are the conditions considered to be important in defining potential coffee yield under changing climate. The studies were under taken at Central Coffee Research Institute (CCRI), Coffee Research Station, Chikkamagaluru district, Karnataka, INDIA to assess the changes in weather pattern particularly on temperature and rainfall and its influence on coffee growth and development. To understand the change in climate and impact of weather parameters four decades of historical weather data were collected from meteorological observatory of the station and analysis were done by standard statistical procedure. Observations on photosynthetic parameters, berry development (Dry weight basis) and extension growth was recorded and assessed in marked plants at fortnightly intervals in arabica and robusta coffee cultivars at CCRI. Trendline analysis of weather parameters for four decades indicated increase in quantum of annual rainfall with change in distribution pattern, raise in both mean maximum and minimum temperature across coffee growing tracts of Western Ghats. The extreme climatic condition and mono shade affected the physiological processes like photosynthetic efficiency and carboxylation efficiency which lead to reduced instantaneous water use efficiency in coffee plants. Studies on coffee berry growth pattern indicated wide variations in growth pattern in robusta coffee indicating more vulnerability of robusta coffee for climate changes like excess deviation of rainfall.
The observations confirmed that the peak period of vegetative growth in coffee is postponed by 15 to 20 days compared to earlier years due to changing monsoon rain fall pattern and rise in temperature. To mitigate this some of the strategies such as better water harvesting structures, improved and rationalized fertilizer use, adequate shade pattern with more diversification, improved soil conservation techniques, uses of plant growth regulators and nutrient sprays could be employed to get maximum crop production under present climate change scenarios.

Keywords- Coffee plants, Climate change pattern, Gas exchange parameters, Mitigation strategies, Mono shade, Vegetative growth.

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Introduction

Coffee is a woody perennial shrub and requires great care in order for farmers to pick consistent and high yields. In the early part of the century, the weather patterns inside coffee forests was predictable and most of the operations like fertilizing, composting, liming and sprinkler irrigation was carried out anticipating the rains. In most cases the farmers were right, even though they were not assisted by computer controlled satellite weather stations. The stable Weather patterns resulted in high yields and most importantly the farming community was a contended lot.

However, for the past 10 -15 years the unpredictable global weather patterns have had a direct bearing on Western Ghats of India. It has reached such unmanageable proportions now a day that many farmers have moved away from plantations seeking refuge in urban areas. Especially, the mindset of the younger generation is in turmoil and utter chaos. The return on investment has seen a sharp decline, resulting in the abandonment of coffee farms.

Change in climate conditions and the frequency of natural disasters in recent times has made it imperative to find lasting adaptation solutions for the several industries in agriculture sector. Given that almost 60 % of the country's population relies on this sector for its livelihood and that it contributes approximately 15.7% of India's GDP An analysis of changes which could impact crop yields and subsequently lead to an instable food security scenario is necessary. Given the rise of global average surface temperatures by 0.74°C in the last 100 years [13], efficient management of the agricultural sector using appropriate adaptation strategies has become a necessity.

Coffee is being cultivated in India for more than 300 years [6] in traditional areas of Karnataka, Kerala and Tamilnadu and at present India is the world's sixth largest producer of coffee [12]. Some 70 percent of Indian coffee production takes place on small farms of less than 10 hectares [5]. Coffee is a main source of economic nourishment for the people of India; it provides a source of revenue for nearly 1.5 million families [2].

Climate change is believed to be one among the numerous factors that may affect global coffee production. According to International Coffee Organization (ICO) climate change would be the most important, considering the large number of small coffee farms whose capacity to implement means and methods to mitigate climate change effects may be low. 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 15 to 24^{0}C and 24 to 30^{0}C with a precipitation 1500 to 2000 mm and 2500 mm per year [18], respectively for arabica and robusta coffee. For robusta the rainfall should be well distributed as the plants are shallow rooted. Climate disturbances have led to fluctuations in yields in almost all the coffee growing countries. Baker P of CAB International is of the opinion that if there is a 3⁰C increase in temperature by the end of this century [3], 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. Rising temperature is expected to make some areas less suitable or completely unsuitable for coffee cultivation, incidences of pest and disease may increase and quality may suffer [17, 10]. Growers may have to depend more on irrigation, putting pressure on water resources. Overall, the production cost is expected to increase. Increase in temperature will force coffee to ripen faster than normal, impacting the inherent quality. Increase in temperature coupled with low rain fall or erratic distribution will affect flowering and fruit set and berry development [15]. In recent years, however, coffee production has been fluctuating as changes in climate affect crops. With above background a study was undertaken to assess the climate change and its impact on coffee grown at Western Ghats of India and technologies for mitigation of effects of climate change for coffee.

Materials and Methods

The studies were under taken at Central Coffee Research Institute (CCRI), Coffee Research Station, Chikkamagaluru district, Karnataka to assess the changes in weather pattern in the coffee growing areas of Western Ghats of India. Four-decade historical weather parameters were collected from meteorological observatory of the station and analysis were done by standard statistical procedure. To find out the impact of rainfall and climatic conditions survey were carried out in different coffee plantations in areas of varied rainfall and elevations. Berry development (Dry weight basis) and extension growth was assessed in marked plants at fortnightly intervals in arabica and robusta coffee cultivars at CCRI. Influences of shade pattern on microclimatic conditions were assessed using a portable photosynthesis and fluorescence system model (LI-COR, LI-6400 USA). Leaf chamber parameters were maintained uniformly throughout the experimentation period. The gas flow rate set in the leaf chamber was 250 ml min^{-1} and boundary layer resistance was 0.08 m^{2}s^{-1} mol^{-1}. When the CO_2 mode was put at ambient, the air CO_2 concentration was around 330-340 ppm. Instrument was calibrated for CO_2 and H_2O before the actual measurements. The instrument measures the parameters such as CO_2 and H_2O concentration in reference and sample air, ambient pressure, PAR, leaf chamber and air temperatures and leaf chamber gas flow rate. Using these data, biophysical formulae and gas constants, the net photosynthesis (*Pn*), stomatal conductance (g_s), transpiration rate (*E*), external CO_2 concentration (*Ca*) and internal Co_2 concentration (C_i) etc. were calculated. Further, instantaneous water use efficiency (P_n/E) and intrinsic water use efficiency *(Pn/gs)* and carboxylation efficiency (*Pn/Ci*) were calculated as the ratio of the above-mentioned parameters. The mesophyll efficiency as a ratio of Ci/gs was calculated [20].

Statistical Analysis:

These data were statistically analyzed by using simple correlation and regression analysis to find out relationship between productivity and climatic conditions. The values of Critical Differences (C.D) are mentioned at a probability level of 0.01 and 0.05. The data was depicted through histographs wherever necessary to differentiate interaction effects of weather parameters easily.

Results and Discussion

Trends of weathers parameters: Trend line analysis of rainfall data of hundred years at CCRI 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 increase was 410.68mm per annum [Fig-1]'. The maximum temperature was increased by 0.8⁰C, 0.5⁰C and 1.0⁰C during summer, rainy and winter periods respectively [Fig-2] compared to last decades (1995-2004) and average maximum temperature increase was 0.8⁰C. Similarly, the summer, rainy and winter period mean minimum temperature was increased by 0.8⁰C, 0.9⁰C and 1.0⁰C respectively [Fig-3] compared to last decades (1995-2004) and average minimum temperature increase was 0.9⁰C. However, over the four decades increase in average rainfall, maximum temperature and minimum temperature were 385.7 mm, 0.52⁰C and 2.20⁰C respectively. The atmospheric relative humidity was found decreased by 0.21%. [Fig-4].

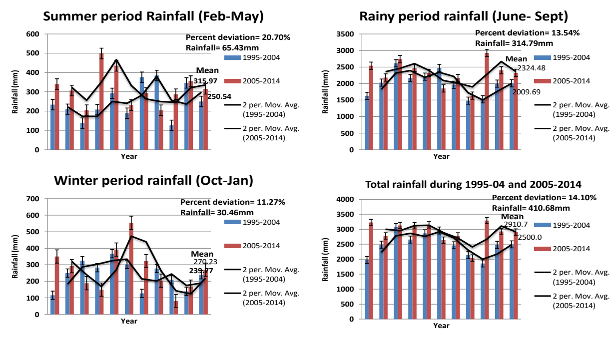

Fig. 1: Rainfall trend for last two decade from 1995 to 2014

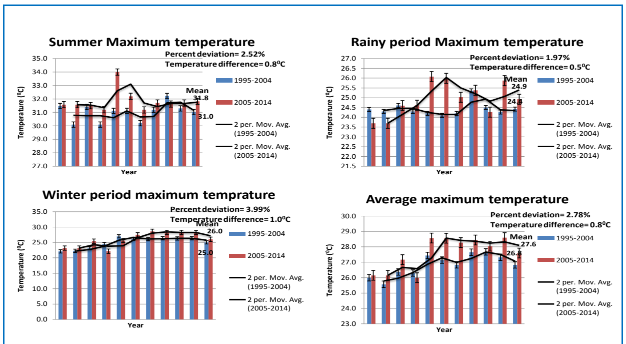

Fig. 2: Maximum temperature trend for last two decade from 1995 to 2014

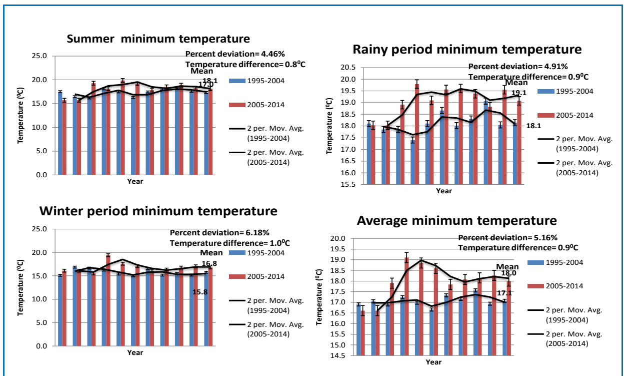

Fig. 3: Minimum temperature trend for last two decade from 1995 to 2014

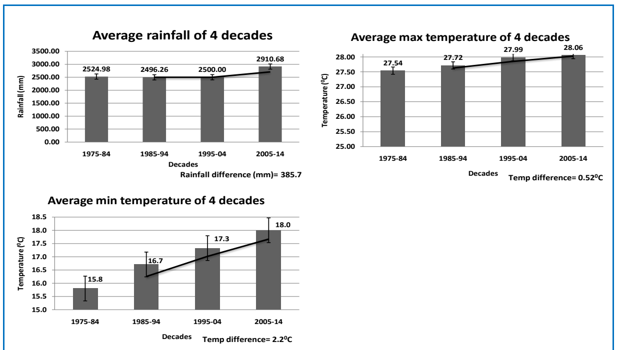

Fig 4. Average rainfall, average atmospheric maximum and minimum temperature trend for last four decades.

Climate change and possible consequences for the coffee crop: Now a day the onset of monsoon is being delayed. The months of May and June are receiving deficit rainfall compared to decades earlier. Intermittent sunshine with frequent showers coupled with high atmospheric relative humidity triggers pathogenicity of opportunistic fungi like *Colletotrichum gleosporoides* which induces stalk rot leading to pre-mature drop of developing berries in coffee [14]. This occurs both in arabica and robusta coffee creating substantial crop loss. Deficit rainfall during early phase of monsoon results in high intensity rainfall during the months of July and August. This type of changing rainfall pattern found to increase the black rot in arabica and robusta coffee by fungus such as *Koleroga noxia* Donk. Due to infection of this disease the leaves and twigs will rot leading to berry blotch and down fall. Due to climate change the premature drop on account of physiological drop, stalk rot and black rot the total crop loss may sometime reach to 30 to 40% [16].

The rise in both minimum and maximum temperature over last four decades, favoured the spread of pests like white stem borer and berry borer which resulted in higher tendency of shifting of arabica to robusta coffee resulting in wider area of low shade. This resulted in change in agro ecosystem. Studies on physiological and microclimatic conditions on S.795 and Sln.12 under different shade patterns indicated that adverse influence of silver oak monoshade on photosynthetic parameters and microclimatic conditions on both S.795 and Sln.12 cultivars even at adequate soil moisture conditions. The net photosynthesis (Pn) was higher under multiple shades of Jack, Ficus, Avocado and Erythrina trees in both S.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 radiation(PAR) and higher relative humidity (RH %). The cultivars under Silver oak mono shade exhibited lower Pn higher E, VPD, leaf temperature, PAR and less RH indicated adverse influence mono shade on coffee plants. The observations on instantaneous water use efficiency (IWUE) and carboxylation efficiency indicated significantly higher IWUE (122.7% and 123.3%) and CE (106.5% and 94.05%) respectively in both the cultivars under multiple shades of jack, avocado, ficus and erythrina trees compared to mono shade implying usefulness of jack and avocado trees as shade canopy to improve crop production of coffee [4] [Table-1 & 2].

Table-1 *Photosynthetic parameters in coffee plants and microclimatic conditions in different shade patterns*

Shade Pattern	Pn µmoles $m^{-2}s^{-1}$	gs moles m^{-2} s^{-1}	Ci (µl l^{-1})	E (mmoles m^{-2} s^{-1})	VpdL	T air ^0C	T leaf ^0C	CO2R ppm	RH-R %	PAR µ einstiens	Spad Chlorophyll
S1	5.18	0.06	205.65	1.51	2.36	31.4	32.51	377.89	51.84	771.4	67.18
S2	5.78	0.05	160.89	1.34	2.4	32.02	32.52	378.63	49.65	824.6	65.35
S3	3.12	0.06	255.5	2.02	3.04	32.72	34.94	368.58	48.06	1134.55	56.65
S4	3.98	0.06	215.14	2.06	3.21	33.31	35.3	369.32	45.13	1416.04	60.26
Sem+/-	**0.59**	**0.002**	**19.42**	**0.18**	**0.22**	**0.42**	**0.76**	**2.7**	**1.41**	**149.67**	**2.4**
SD	**1.19**	**0.005**	**38.83**	**0.36**	**0.44**	**0.83**	**1.51**	**5.39**	**2.82**	**299.35**	**4.8**

S1- S,795Multipleshade/ Jack,Ficus,Avacado,Erithrina, S2- Sln.12Multipleshade/Jack,Ficus,Avacado,Erithrina
S3- S.795 Silvar Mono shade & S4- Sln.12 Silver mono shade
Pn- Rate of Photosynthesis, gs- Stomatal conductance, Ci- Internal CO_2, E- Transpiration rate, Vpd- Vapour pressure deficit, T air- Air temperature, T leaf- Leaf temperature, CO_2 R- Reference CO_2, RH R- Reference relative humidity, PAR- Photosynthetically active radiations, SPAD- Soil plant analytical device.

Table-2 *Instantaneous water use efficiency (IWUE) and carboxylation efficiency (CE) in coffee plants under different shade patterns.*

Shade pattern	Instantaneous water use efficiency (µ moles $mmol^{-1}$)	Carboxylation efficiency µmoles $m^{-2}s^{-1}$(µl l^{-1})$^{-1}$
S,795Multipleshade/ Jack,Ficus,Avacado,Erithrina	3.43	0.0252
Sln.12Multiple shade/Jack,Ficus,Avacado,Erithrina	4.31	0.0359
S.795 Silvar Mono shade	1.54	0.0122
Sln.12 Silver mono shade	1.93	0.0185
Sem+/-	**0.64**	**0.05**
SD	**1.29**	**0.01**

Similarly, studies were conducted on berry growth pattern in arabica (S.795) and robusta (S.274) coffee under changing climatic conditions indicated berry growth with two slow (Jul to Sept 1st fortnight and Oct to Nov 1st fortnight) and two rapid growths in both arabica and robusta coffee [Fig-5 a&b]. During 2014 season the berry dry matter accumulation was higher in both arabica and robusta coffee compared to 2011, 2012 and 2013 seasons. Also, the varied distribution of moving average trend lines clearly indicated seasonal variation in berry growth pattern in both the cultivars. Such differences in berry growth pattern might be due to differences in rainfall pattern, quantum of rainfall, wet feet conditions atmospheric temperature and also sunshine hours during monsoon period. The wide variations of growth trend lines in robusta coffee indicated more vulnerability of robusta coffee for climate changes [20].

Observation on extension growth revealed that the percent increase in leaves indicated maximum leaf production in arabica coffee during October month in both the seasons reaching to its peak in 2nd fortnight of October [Fig-6a]. Similar trend was also noticed with respect to number of nodes per branch [Fig-6b]. The robusta coffee also showed similar pattern of growth during both the seasons [Fig-6 c&d]. The extension growth was high during 2011 season compared to 2012 season during the month of October. This could be due to low cropping season during 2011 season compared to 2012 season. However, during 2012 monsoon period both genotypes showed higher growth compared to 2011 season. This could be due to low rainfall and delayed onset of monsoon during 2012 season. A deficit rain fall of 65.89, 55.75 and 40.22% was noticed during May, June and July months respectively during 2012 season compared to 2011 season.

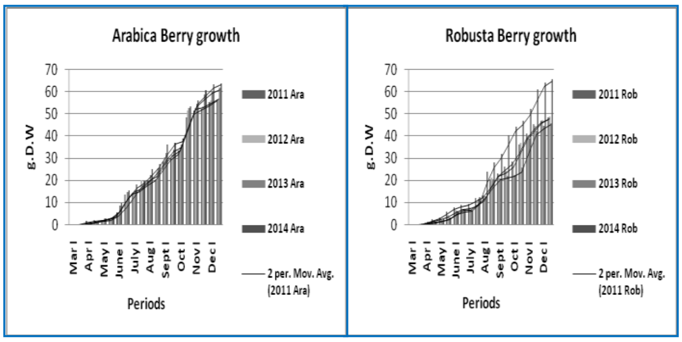

Fig-5 Berry growth in arabica and robusta coffee under changing climate

The low number of rainy days, deficit rainfall coupled with intermittent sunshine and adequate soil moisture might have encouraged resumption of vegetative growth during 2012 season in both the genotypes compared to 2011 season. However, during summer months of 2012 season [18] the vegetative growth was less in both the genotypes probably due to prolonged winter with low atmospheric temperature and soil moisture stress also higher crop during 2012 season compared to 2011 season [1]. The observations further confirmed that the maximum vegetative growth in coffee is postponed by 15 to 20 days compared to earlier years which could be due to changing monsoon rain fall pattern [9]. This invite rescheduling of fertilizer application in coffee. These results of two seasons clearly indicated that the extension growth depends on monsoon rainfall pattern, crop load, atmospheric temperature, duration of prevalence low temperature, soil moisture content and receipt of summer showers in both arabica and robusta coffee under changing climatic conditions in coffee growing areas.

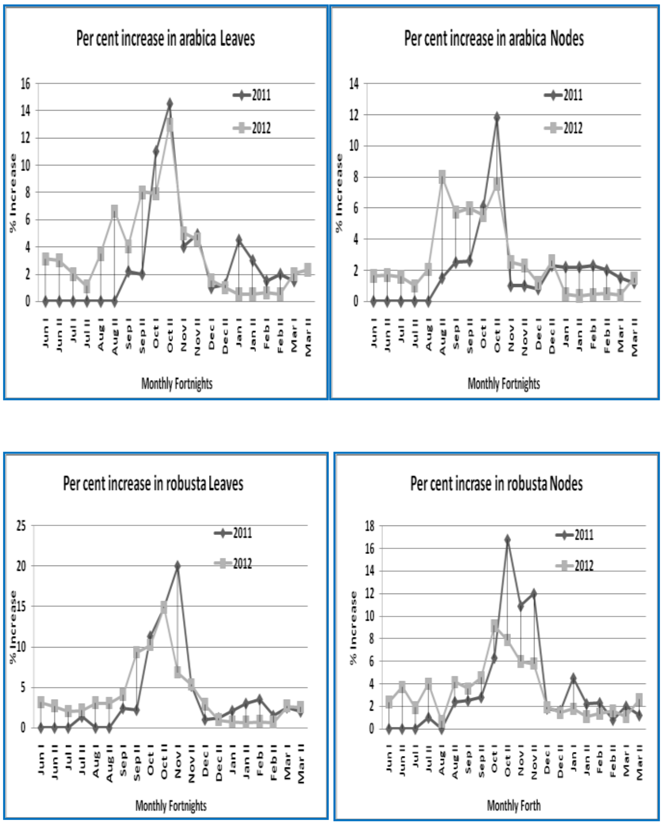

Fig-6 (a,b,c &d)Seasonal variation in extension growth of arabica and robusta coffee under climatic conditions

Agronomic technologies for mitigation of effects of climate change for coffee.

Mitigation strategies for climate change include interventions to reduce the sources or enhanced the sinks of greenhouse gases found to have marked management components. The components like conservation of natural resources such as use of water harvesting, improved fertilizer use, adoption of ecofriendly improved plant protection measures, maintenance of useful shade pattern and conservation techniques need to be given priority [8]. These strategies are equally consistent with the concept of sustainability. Adaptation strategies include initiatives and measures to reduce the vulnerability of agro-ecosystems to projected climate change, such as changing varieties, development of newer varieties having tolerant to higher temperature and resistant to white stem borer and other pest and diseases, altering the timing of cropping activities, improving the effectiveness of pest, disease and weed management practices, making better use of seasonal climate forecast etc [7]. It is essential to develop and integrate Agriculture Mitigation and Adaptation Frameworks (AMAF) for climate change into sustainable development planning at the national and regional levels to cope with the projected impacts of climate change for coffee [11].

Conclusion

The results of the study indicated changes in rainfall pattern and elevation in atmospheric maximum and minimum temperature in coffee growing regions of Western Ghats of India. The changes in climatic conditions affected growth pattern, berry development and out turn besides bean physical characteristics in coffee. The suitable mitigation practices such as adequate shade with multiple shade pattern, water harvesting, improved fertilizer use, use of biofertilizers, adoption of drought mitigation practices like uses of plant growth regulators and nutrient sprays helps in overcoming the adverse influence of climate change in coffee.

***Research Category:** Coffee Climate Change

***Application of research:** Climate change and possible consequences for the coffee crop

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Author Contributions: All author equally contributed

Author attribution: Acquisition, analysis, drafting, interpretation of the data and worked as team member in the course of investigation.

Author statement: All authors read, agree and approved the final manuscript

Ethical approval: This article does not contain any studies with human participants or animals performed by any of the authors.

Conflict of Interest: None declared

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