Impacts of Climate variability on Agriculture in Kerala

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DECLARATION

I hereby declare that the thesis entitled, **"Impacts of Climate variability on Agriculture in Kerala"** is an authentic record of research work carried out by me under the supervision and guidance of Dr.GSLHV Prasada Rao, Professor of Agricultural Meteorology, Kerala Agricultural University and Dr.H.S.Ram Mohan, Professor of Meteorology (Retired), at the Department of Atmospheric Sciences, Cochin University of Science and Technology, in partial fulfillment of the requirements for the award of the Ph.D in the Faculty of Marine Sciences and no part thereof has been presented for the award of any other degree in any University / Institute.

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CERTIFICATE

This is to certify that this thesis entitled, **"Impacts of Climate Variability on Agriculture in Kerala"** is an authentic record of the research work carried out by Mr. Gopakumar C.S under our supervision and guidance at the Department of Atmospheric Sciences, Cochin University of Science and Technology, in partial fulfillment of the requirements for the Ph.D. Degree of Cochin University of Science and Technology under the Faculty of Marine Sciences and no part thereof has been presented for the award of any degree in any University.

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Introduction

The State of Kerala, is a tiny strip of land having an area of 38.86 lakh ha (1.185% of the national land area), situated west of Western Ghats. It is located in the humid tropics between the latitudes of 8°18’ and 12° 48’N and longitudes of 74°28’ and 77°37’E. The State of Kerala, named as “Gods own country” and the “Gateway of monsoon in India” is one of the unique regions in the humid tropical monsoon climates that enjoys high solar radiation and warm temperature round the year. The State has rich bio-diversity and tropical rain forests and is spread in 13 agro-ecological zones under the humid tropics. The name of the State “Kerala” is derived from “kera” meaning coconut. High rainfall with uni and bimodal distribution, undulating topography, mosaic of soil types and sharp changes in physiography (below msl to 2500 m amsl), together with 44 rivers, many fresh water lakes and estuarine backwaters engender contrasting ecological units congenial for high biological activity, manifested in rich biodiversity. Combinations of these endowments multiply into innumerable resource configurations that enable various species of crops in the State. Though Kerala is identified as a plantation State, the major staple food crop is rice. Cash crops include coconut, arecanut, rubber, cashew, tea, coffee and cocoa. Black pepper, cardamom, cinnamon, clove, turmeric, ginger, nutmeg and vanilla are major spice crops.

Out of a total area of 38.86 lakh ha, net sown area is about 56 per cent. Forest occupies about 28 per cent. Agriculture and forest sectors together account for more than 84 per cent of the land area.

The food crops comprising of rice, pulses, miner millets and tapioca occupy only 11.86 per cent, out of a gross cropped area of 26.69 lakh ha in 2009-10. The State of Kerala which has low base in food production is facing serious challenges in retaining even this meagre area. Agricultural economy of the State is undergoing structural transformation from the mid seventies by switching over a large proportion of its traditional cropped area under rice and tapioca to more remunerative crops like coconut and rubber. The area under rice has been declining consistently over the last few decades while the area under commercial crops in general has increased considerably during the last two decades. There was a phenomenal incremental growth in the case of rubber since last one decade. India is the fourth largest producer of annual rubber with a share of eight per cent in the world after Thailand. India is at the same time the second largest consumer of natural rubber after china. Kerala accounts for 78% of the area under rubber in the country. The increasing trend in productivity continued during 2008-09. The higher prices in the international market are reflected in the domestic market also.

In Kerala, *mundakan* (second crop) season accounts for the highest share in production with 45.51 per cent followed by 32.1 per cent in *virippu* and 22.4 per cent in *puncha.* In order to increase the food production in the State, a major food security project was launched in 2008-09 covering paddy crop. Though a perceptible improvement in the area is visible in the State, the increase in paddy production was only marginal due to weather vagaries. The area and production of rice during 2007-08 was one of the lowest. It was attributed to the heavy rainfall during 2007, followed by unusual summer rains in March 2008. Unless the weather related issues are addressed under the projected climate change scenario with crop calendar, increase in paddy production is likely to be not at expected levels to meet the growing demand for foodgrains.

Plantation crops in general are export oriented or import substituting and therefore assume special significance from the national point of view. It is estimated that nearly 14 lakh families are dependent on the plantation sector for livelihood. Kerala has a substantial share in the plantation crops in the four plantation crops of rubber, tea, coffee and cardamom. These four crops together occupy 6.89 lakh ha, accounting for 31.58% of the net cropped area in the State and 43% of the area under these crops in the country. Kerala's share in the national production of rubber is 91%, cardamom 75%, coffee 22% and tea 5% during 2008-09. Another important crop in Kerala is coconut which is grown in an area of 1.90 million ha producing 15730 million nuts with a per hectare productivity of 8303 nuts in 2008-09. Kerala's share in area as well as production of coconut in the country is declining over time. The share of area declined from 57 per cent in 1991-92 to 42 per cent in 2008-09, while the share of Karnataka and Tamil Nadu together increased from 29 per cent in 1992-93 to 42.68 per cent in 2008-09. With coverage of 7.79 lakh ha, coconut occupies 36 per cent of the net cropped area. The productivity levels in the State are also lower than other major producing states. The productivity in Kerala is 11.07 per cent lower than national average in 2008-09. The productivity in Maharashtra in 2008-09 was 8338 nuts and 13771 nuts in Tamil Nadu while in Kerala, it was only 7365 nuts.

Kerala is the leading producer of black pepper accounting for more than 90%. Black pepper produced in Kerala fetches a premium price in international market in view of its intrinsic quality. The pepper production was just 22.63 thousand tonnes during 1952-53 and a low of tonnes only was recorded during 1984-85. It was the lowest production year. The crop is highly sensitive to rainfall distribution. It was attributed to unusual pre-monsoon showers followed by dryspell during the re[productive phase of black pepper. There was again an increase in area accounting to 63.9 thousand tonnes in 2007-08. Occurrence of insect, pest and diseases is a threat to black pepper cultivation in the state. The quality of black pepper is very important since it is an exported commodity.

Area under cashew has been declining steadily since 1990s and reached the level of 79.4 thousand ha during 2001-08. The area decline was 20% during the last two decades. India's share in the world raw cashew nut production accounts to about 25 per cent. Maharashtra contributes to 32.45% to total cashew production and area of 19% of the total. It has the credit of having the highest productivity (1500 Kg/ha). Kerala's share to cashew production is only 11% from an area equivalent to that of 8% of total area under cashew in the country. Its productivity is compared to that of national average (900 kg/ha). More than 50% of the state's cashew production is from northern districts viz., Kannur and Kasaragod. India exported cashew kernels worth 2905.82 crores during 2009-10 and imported raw nuts worth 3037.35 crore resulting in a net foreign exchange loss of 131.53 crore. USA is the major export market with 28 per cent export share followed by UAE (16.8%).

The productivity of cardamom which was more or less stagnant around 50 Kg/ha in the 1980s has improved to the level of 206 Kg/ha in 2008-09 and declined to 188 Kg/ha in 2009-10. The share of Kerala in production at the all

India level increased from 28% in 1992-93 to 56% in 2008-09. India has earned Rs.16, 570 crores from the export of small cardamom during 2009-10. On export front, cardamom has been facing competition from Guatemala although the quality of Guatemala cardamom is inferior.

The area under tea cultivation in Kerala accounts for 0.37 lakh ha, as against the total area of 5.11 lakh ha in the country. Kerala's share in the production of tea is only 6.6 per cent in 2007. There is large fluctuation in production and it ranged from 64.8 Kg/ha in 1995-96, reaching 69.1 M.Kgs in 2000-01 which declined to 57.81 M Kg in 2009. India has earned Rs.2381.8 crores on account of export of tea during the financial year 2008-09. In the case of south India, the export earning is 821 crores.

Coffee is a major beverage crop in Kerala. The area under coffee in Kerala was 0.85 ha out of 3.99 lakh ha in the country in 2009-10, which works out to 21 per cent. The share in production is 20.5 per cent during 2009-10. The major share (95 %) grown in Kerala is Robusta. The productivity of coffee in Kerala is 705 Kg/ha which is lower than that of national level (826 Kg/ha). Coffee provides opportunities for livelihood to nearly one lakh families including agricultural labourers. In Kerala, coffee is also one of the small holder plantation crops with nearly 76,000 holdings coming under the category with an average size of 1.1. Ha. Coffee is a highly export dependent crop and more than 80 per cent of domestic production is exported.

The State is more or less an agrarian economy. The provisional income during 2009-10 from the agricultural sector is estimated as Rs.16, 683.91 crores, which is 0.25 per cent higher than that of previous year. The share of agriculture and allied sectors in Gross State Domestic Production

(GSDP) indicated a continuous decline in the State. The share was only 11.54 per cent during 2009-10 (Economic Review, 2010).

1.1 GLOBAL CLIMATE CHANGE SCENARIO

Climate change and climate variability have become a reality. Changes are noticed in all sectors of life including agriculture. According to IPCC (2007), climate change refers to a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer). Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use. Climate variability is the variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all temporal and spatial scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability). The IPCC (2006) projected the rate of warming for the 21st century to be between 0.8 and 4.4°C at various stabilized levels of CO_2 in atmosphere and it is most likely to be 3°C by the end of this century. It could cost global economy almost $7 trillion by 2050, equivalent to a 20% fall in growth if no action is taken on greenhouse gas emissions. If action is taken it will cost only $350 billion due to climate change already taken place, just 1% of GDP.

Anthropogenic activities over the last century have contributed towards increase of atmospheric concentration of the greenhouse gases (GHGs) and thereby led to an enhancement of natural greenhouse effect. Increase in concentration of the greenhouse gases in the atmosphere has led to the warming of the earth's surface and atmosphere and thereby threatening to change the climate of the entire earth system. Increased levels of these gases beyond their natural levels due to uncontrolled human activities such as burning of fossil fuels, increased use of refrigerants and enhanced agricultural activities caused climate to change to the present form.

1.2 CLIMATE CHANGE SCENARIO IN INDIA

A marked increase in rainfall and temperature is projected in India during the current century. The maximum expected increase in rainfall is likely to be 10-30% over Central India. Temperatures are likely to increase by 3-4°C towards the end of the Century. It is more pronounced over northern parts of India. It is expected that the area averaged mean annual surface air temperature is likely to increase over the land regions of the Indian sub continent between 3.5°C and 5.5°C by 2080s. These projections showed more warming in winter season over summer monsoon. The spatial distribution suggests that north India may experience an annual mean surface warming of the order of 3°C or more by 2050s and over southern peninsula it is 2°C during winter.

In the case of rainfall, a marginal increase of 7 to 10 per cent in annual rainfall is projected over the sub continent by the year 2080. However, the study suggests a fall in rainfall by 5 to 25% in winter while it would be 10 to 15% increase in southwest monsoon rainfall over the country. The date of onset of monsoon over India could become more variable in future. Because of the increasing concentrations of the radiative or greenhouse gases, there is much concern about future changes in our climate and direct or indirect effects on society linked sectors like health, agriculture including animal agriculture, biodiversity, marine ecosystem, forestry, fisheries, water resources and sea level rise (Garg *et al.,* 2001; IPCC, 2001; Krupa, 2003; Aggarwal, 2003; Rao, 2011). Under the projected climate change scenario, Indian agriculture is subjected to vagaries of weather. It will have impacts on the agriculture scenario of Kerala too, as the State's economy is to a greater extent dependent on plantation sector

1.3 CLIMATE CHANGE SCENARIO IN KERALA

Kerala is the land of monsoons. It is also one of the wettest places in the world, where annual rainfall is of the order of 3000mm. About 68 per cent of the rainfall is obtained during southwest monsoon while 16 per cent in post monsoon and the rest from summer (14 per cent) and winter rainfall (2 per cent). Rainfall pattern in recent years in Kerala exhibits uncertainties. Since last one decade, only one year (2007) recorded excess rainfall (27.9%). The years 2002 (37.7% deficit) and 2004 (36.7 % deficit) were declared as the monsoon deficit years in Kerala during which surface water sources dried up and led to hydrological drought during summer 2004 as consequence of monsoon rainfall deficit from 1999 to 2004. For the first time, all the major water reservoirs in Kerala were full in September after a gap of six years during this decade. Rao, *et al.,* (2009) reported that there exists a cyclic trend in annual rainfall with a declining trend in annual and southwest monsoon rainfall and an increasing trend in post monsoon rainfall since last 50-60 years.

Onset of monsoon also appears to be erratic in recent years. Frequent failure or break in monsoon across the State led to water scarcity and adversely affected hydro power generation. A clear upward trend in surface air temperature across the West Coast between 1961 and 2003 by 0.8°C in maximum and 0.2°C in minimum temperature with an increase in average surface air temperature of 0.6°C was noticed. According to India Meteorological Department (IMD), during the last 43 years, the mean maximum temperature over Kerala has risen by 0.8°C, the minimum by 0.2°C and the average by 0.5°C, indicating that the temperature trends in Kerala followed the trends of West Coast. . February and March are the hot months of Kerala with a mean maximum of 33°C. Palakkad recorded the highest of 41°C on 26th April 1950. This was 8°C more when compared to the normal maximum temperature in March. Similar temperatures were recorded over the Palakkad region in February and March 2004, which was one of the severe summer droughts in Kerala. Day time temperatures during March 2010 often crossed 40°C at many places in Palakkad and Thrissur Districts. For the first time in the history of Kerala, sunburn events were reported during March, 2010 in Palakkad District. The year 1987 was the warmest year over Kerala. The State experienced severe summer droughts in 1983 and 2004 while floods during the monsoon season of 2005, 2007, 2009 and 2010. Of course, floods are not uncommon in lowlands of Kerala as it receives heavy rainfall in almost all the years.

Crop losses were considerably high during these weather extremes. The heavy monsoon rainfall in 2007 followed by unusual summer showers in March 2008 together adversely affected the paddy production of the State. The lull in monsoon over Kerala during 2002 followed by floods in October 2002 due to cyclonic storm over Karnataka coast devastated seasonal crops and plantations to a considerable extent. Kannur received 370 mm of rainfall on 14th October 2002, which was the highest and not received since 1924. The widespread post monsoon rainfall during 2010 devastated the paddy fields especially in upper Kuttanad and Kole lands of Thrissur. The State received record rainfall during post monsoon 2010. Low lands of southern districts were flooded due to the prolonged rainfall during November, 2010. Are these frequent weather aberrations like monsoon uncertainties, floods and droughts and sunburns and heat load during summer could be as a part of global warming and climate change? In the first report on “Impact of climate change in four regions of the country” submitted to the Government of India by the Indian Network for Climate Change Assessment (INCCA), it has been pointed out that reduced rainfall, increased atmospheric temperature and flooding due to sea level are the climate change scenarios for the Western Ghats and Kerala in the next 20 years. The minimum surface air temperature in the Western Ghats region may rise by 2 to 4.5°C. The average temperature in the region bordering Kerala is likely to rise by 1 to 3°C. The number of rainy days is likely to decrease along the entire Western Coast, including the Western Ghats. The rice fields in the northern districts of Kerala may witness an increase in production. If the sea level rises by one metre, 169 sq km of the coastal region surrounding Kochi will be inundated.

Under the projected climate change scenario, it is certain that the temperature is likely to increase by 2°C by 2050. An increase of surface air temperature by 2°C would have tremendous adverse influence on the crops growing across the State. Even now, the thermosensitive crops across the highranges are under threat as the temperature range is widening. The temperature range is nothing but the difference between the day maximum and the night minimum temperature. Temperature rise not only affects agricultural sector, but also will have tremendous deleterious effects in health sector. Proper adaptation strategies need to be developed in the event of projected temperature rise in Kerala for sustenance of agricultural production.

The wetlands in Kerala are rich sources of water during summer and act as sink during monsoon season. The wetlands comprise all types of natural and man made water bodies including paddy fields, reservoirs, mangroves, rivers, lakes, inundated areas and kole lands. Such wetlands are fast declining in Kerala (Fig.1.1). Decreasing wetlands might be one of the reasons for frequent floods and droughts in Kerala in recent years.

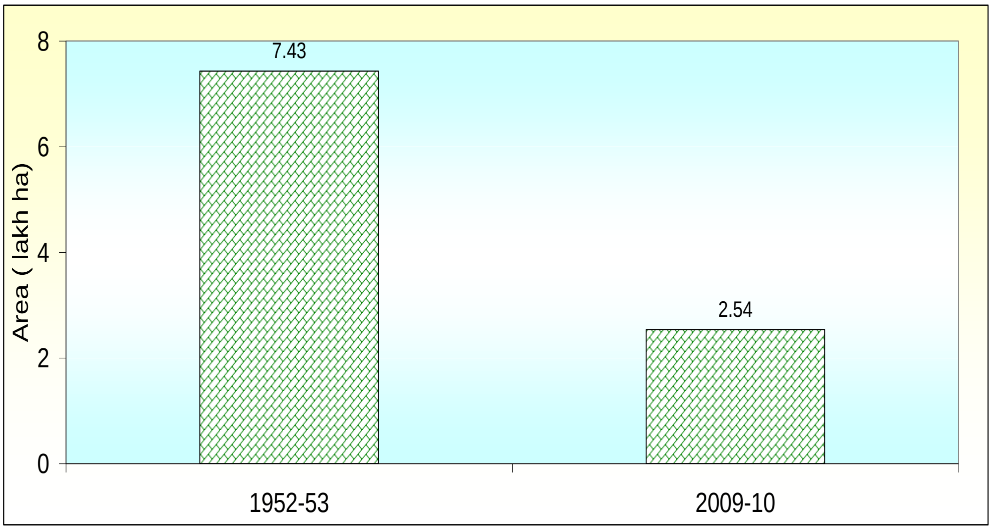


Fig.1.1 Wetland decline in Kerala 1952-53 to 2009-10

Climate change/variability and deforestation over a period of years have changed the typical agro-ecosystems of Wayanad. Paddy fields have been converted into banana garden. Excessive use of agrochemicals and pesticides, large-scale sand mining from rivers have been identified as the causal factors for severe drought in summer 2004 in addition to decline in rainfall. Groundwater depletion in Wayanad was so much (25%) due to over exploitation. Rise in maximum temperature and fall in minimum temperature are the trends in Idukki agro-ecosystem, and thus the natural habitat of cardamom is also in peril. Widening in temperature range along with deforestation may be detrimental to thermo-sensitive crops like cardamom, coffee, tea, cocoa and black pepper across the highranges of Kerala.

The forest cover of Kerala declined from 70 per cent to 24 per cent over a period of one- hundred- and - fifty years (Fig.1.2).

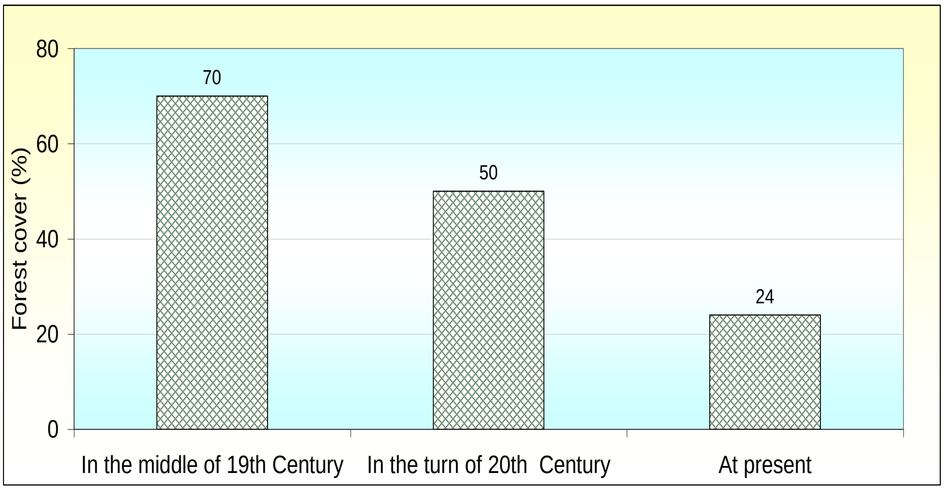


Fig.1.2 Forest covers over Kerala (%)

The Economic Review prepared by the State Planning Board, 2003 warns that a third of the State's biodiversity would vanish or would be close to extinction by 2030 unless steps are taken to check extinction of species. Of the 300 rare endangered species or threatened species in the Western Ghats, 159 are in Kerala. Of these 70 are herbs, 23 climbers, eight epiphytes, 15 shrubs and 43 trees. Besides, 10 species of fresh water fish have been identified as most threatened. Kerala has a flora of 10,035 species, which represents 22 per cent of Indian flora. Of these, 3872 are flowering plants of which 1272 are endemic. 102 species of mammals, 476 birds, 169 reptiles, 89 amphibians and 262 species of fresh water fish are reported from Kerala. The review recalls that during the 20th century, at least 50 plant species have become extinct in the country. Describing a conservation strategy, the review says that ecologically sensitive areas have to be identified with reference to topography, hydrological regimes and have to be networked with species diversity in order to conserve the extinction of rare species of flora and fauna of the State under the projected climate change scenario.

An increased demand and unregulated exploitation are threatening to accelerate depletion of groundwater resources in Kerala. Because of the heavy extraction of groundwater, the water level has fallen alarmingly. The destruction of forests in the catchment areas has led to the drying up of reservoirs and the extensive sand dredging has drastically reduced rivers' water holding capacity and percolation to groundwater. Groundwater is depleting at a faster rate than that of its recharge. Some of the reasons being decline in rainfall, more run off, over use of water for irrigation, more land is brought under irrigation for cultivation; increased demand for drinking water for the growing population, deforestation, and riverbed based sand mining, decline in wetland area and disappearance of lakes and ponds. In short, the climate change related issues over Kerala may be summarized as below:

- Decline in rainfall, wetlands, land and ocean biodiversity
- Increase in temperature and sea level
- Floods and droughts, landslides, groundwater depletion and saline water intrusion
- Decline in forest area and frequent forest fires
- Rice, cashew, cocoa, coffee, tea, cardamom and black pepper are likely to be under threat

The changes in rainfall and thermal regimes may result to shifting of climate from wetter to drier zones within the humid type of climate. Therefore, there is a need to study in detail on rainfall and temperature trends across the State on zone-wise. The climate shifts over Kerala, if any, and occurrence of droughts and floods in the State have to be brought out in projected climate change scenario. The impact of climate change/variability on crops grown in the State, including food security of the State has not been attempted under the projected climate change scenario. Keeping this in view, the present investigation was taken up with the following objectives:

- To update the data on regional climate change/variability across the country

- To study the climate change / variability zone - wise within the State of Kerala and understand the vulnerable zones to climate change/ variability

- To study the impact of climate variability / change on plantation crops and food security

The results of the study are likely to provide

- an insight into the trends of rainfall and temperature at the national and zonal level

- a comprehensive picture on climate change/climate variability over Kerala

- the location - wise trends in rainfall and temperature regimes and to identify the vulnerable areas susceptible to climate change across the State of Kerala

- impact of climate variability/change on major crops that are grown in Kerala

- Future strategies in relation to climate change issues

Chapter 2

Review of Literature

Extensive survey has been conducted to collect literature in all the aspects of study. Literature on climate change / climate variability has been collected relevant to the objectives of the study undertaken.

2.1 TEMPERATURE VARIABILITY

Pant and Kumar (1997) have shown that there has been an increasing trend of mean annual temperature over India at the rate of 0.57°C/100 years. The trend and magnitude of global warming over India / Indian sub continent over last century is broadly consistent with the global trend and magnitude. They have further reported that in India, warming was found to be mainly contributed by the post monsoon and winter seasons. The monsoon temperatures do not show a significant trend in any part of country except for significant negative trend over northwest India.

Samra *et al (*2004) have observed that crop yield loss varied between 10 and 100% in the case of horticultural and seasonal crops when there was a cold wave from December 2002 to January 2003 in some parts of Jammu, Punjab, Haryana, Himachal Pradesh, Bihar, Uttar Pradesh and north Eastern States. The occurrences of high maximum temperature in March 2004 adversely affected the crops like wheat, apple, mustard, rapeseed, linseed, potato, vegetables, pea and tea across the state of Himachal Pradesh in India. The yield loss was estimated between 20% and 60%, depending upon the crop (Prasad and Rana, 2006). Such heat and cold waves are not uncommon in northern States.

Hingane *et al.,* (1985); Kumar and Hingane (1988); Pant and Hingane (1988); Kumar and Parikh (1998); Sanghi *et al.,* (1998); Kumar *et al.,* (2002); Gadgil and Dhorde (2005); Kothawala and Kumar (2005); Ramakrishna (2007) studied from time to time on temperature variability across the country. It is inferred from the above studies that the rate of increase in temperature varied depending upon the data set, location, region and season. Overall, the warming trend is evident across the country and the rate of increase in temperature was high in recent years though some locations showed cooling trend. The trend is visible in the case of maximum temperature while not so in the case of minimum temperature. The temporal and spatial variations in temperature are significant depending upon the season and the region. The spatial patterns of maximum temperature indicated that the Central India experiences more than 45°C while 35-40°C along the West Coast and above 25°C in Himachal Pradesh in north India (NATCOM Report, 2004). Some stations of the Indian Peninsular Plains also showed a falling trend in temperature. Several models indicated that the increase in temperature is likely to be around 3°C over the Country by 2100A.D.

2.2 RAINFALL VARIABILITY

Several workers conducted studies on different aspects of Indian monsoon - its onset, intra-seasonal and inter-annual variability and general characteristics, periodicities and inconsistencies of rainfall. Monsoon events and periodicities were studied by Rajeevan (2001); Pai and Rajeevan (2007); Raju *et al.,* (2008). The Indian monsoon rainfall is highly influenced by atmospheric factors such as sea surface temperature variations (Gosami *et al.,* 2006). Variation in occurrence of rainfall has been studied widely by several authors across the globe. He Jin-Hai (2009) in his paper has reviewed the field experiments conducted investigating the Asian-Pacific monsoon. The onset and the seasonal march of the Asian summer monsoon and the annual cycle of active and break periods of the monsoon, which are characterized by precipitation maxima and minima, have been reported. Parthasarathy and Dhar (1975) using the data from about 3000 rain gauges for the period from 1901 to 1960 and shown that the mean values of the annual rainfall for the 30 year period from 1931-1960 showed a significant increase of about 5 per cent.

Kumar *et al.,* (1992) reported that in India in the case of rainfall, the observed southwest monsoon seasonal rainfall at all India level does not show any significant trend. Understanding the regional level of rainfall trend using long period data is of immense importance for countries like India, where the economy is dependent on agriculture. Krishnamurthy and Shukla (2000) studied the intra-seasonal and inter-annual variability of rainfall over India and found that there is considerable variability in the spatial patterns of the rainfall anomalies over India on both daily and seasonal time scales. Trend analysis studies carried out at for the 36 subdivisions of the country revealed that the contribution of June and July rainfall is decreasing while that of August and September is increasing (Guhathakurta and Rajeevan, 2006). The contribution of June rainfall is increasing in 19 sub divisions and decreasing in 17 sub divisions. July rainfall is decreasing in Central and west peninsular India, while the contribution of August rainfall is increasing in all these sub divisions (south interior Karnataka, East MP, Vidarbha, Madhya Maharashtra, Marathwada, Konkan and Goa and North interior Karantaka).

Studies related to changes in rainfall over India have shown that there is no statistically significant trend in the all India rainfall (Mooley and Parthasarathy, 1984; Thapliyal and Kulshrestha, 1991). Study of Sarkar and Thapliyal (1988) and Srivastava *et al*., (1988) indicated no trend in all India summer monsoon rainfall. In terms of changes in rainfall over India, no clear trend of increase or decrease in average annual rainfall over India has been observed. Based on an analysis carried out using the rainfall data for 1100 stations across India, it showed that pockets of rainfall deficit over eastern Madhya Pradesh, Chhattisgarh and Northeast region in central and Eastern India especially around Chhattisgarh and Jharkhand (Rao, *et al.,* 2008). Rajeevan (2001) reviewed the status problems and future prospects of long range forecasts of Indian summer monsoon. Prediction of Indian monsoon variability is found to be sensitive to the initial conditions, suggesting that chaotic internal dynamics may ultimately limit the predictability of India monsoon. Raju *et al.,* (2008) discussed the mean conditions of surface meteorological fields during active and break monsoon conditions of Indian monsoon. Naidu, *et al.,* (1999) studied the trends and periodicities of annual rainfall for 29 sub-divisions of India and all India (area-weighted average of the sub-divisions) using time series of data for 124 years (1871-1994). Pant and Hingane (1988) studied the relation between the long term variability of the Indian summer monsoon and related parameters and observed that the relationship between Southern Oscillation Index and Equatorial Pacific Sea surface temperature and Indian summer monsoon seems to be dominant on inter-annual scale. Yin (1949) was the first to link the process of monsoon onset to the displacement of westerly troughs in the circumpolar westerlies and shift of the Sub Tropical Jet (STJ) to the north of the Himalayan periphery. Gadgil (1988) discussed different aspects of intra-seasonal and inter-annual aspects of Indian summer monsoon. An overview of impact of climate variability on agriculture was given by Sikka and Pant (1990). Borgoankar and Pant (2001) have reported the trendless nature of the Indian monsoon rainfall since 17th century based on proxy data with large inter-annual fluctuations.

Unlike in temperature trends, rainfall trends are uncertain at several locations (Kumar *et al*., 2002; Rao *et al*., 2008). Studies revealed that the annual rainfall as well as southwest monsoon rainfall over Kerala is declining while post monsoon rainfall declines increasing (Krishnakumar *et al*., 2008 & 2009).

The inter-annual monsoon rainfall variability in India leads to large-scale droughts and floods, resulting in a major effect on Indian foodgrains production (Parthasarathy and Pant, 1985; Parthasarathy *et al.,* 1992; Selvaraju, 2003; Kumar *et al.,* 2004) and on the economy of the Country (Gadgil *et al.,* 1999a; Kumar and Parikh, 1998). Studies carried out for the Country indicate that rice and wheat yields could decline considerably with climate change (Sinha and Swaminathan, 1991; Aggarwal and Kalra, 1994; Kalra and Aggarwal, 1996; Lal *et al.*, 1998). These impacts are either direct effects due to climate change such as changes in temperature, rainfall or carbon dioxide concentrations or indirect effects through changes in soil, distribution and frequency of inset, pest and diseases, or weeds and water stress. Mall and Singh (2000) observed that small changes in the growing season temperature over the years appeared to be the key aspect of weather affecting yearly wheat yield fluctuations. Pathak *et al.,* (2003) concluded that the negative trends in solar radiation and an increase in minimum temperature, resulting in declining trends of potential yields of rice and wheat in the Indo-Gangetic plains of India. Since solar radiation is closely related to crop growth, any decrease in this will significantly reduce agricultural productivity. The accompanied increase in minimum temperatures increase maintenance respiration requirement of the crops and thus further reduces net growth and productivity (Aggarwal, 2003).

Shortfalls in rainfall can reduce irrigation water supplies, leading to reduction in areas under irrigated crops and potentially increased areas under rain-fed crops in the subsequent season (Kumar *et al*., 2004). They concluded that under future scenarios of increased greenhouse gas concentrations (GHG) indicate marked increase in both rainfall and temperature into the 21st century, particularly becoming conspicuous after the 2040s in India. Mall, *et al.,* (2005) observed that the agricultural impacts of climate change in India are uncertain.

All the projections on climate change are based on General Circulation Models. All models project increase in temperature over the Country under different GHG emission scenarios. Rainfall variability is felt at different zones. Though the GCMs have been successful in depicting the gross features of the observed large scale climatolological features, there is large uncertainty associated with these projections on regional scale, since the GCMs are yet to realistically reproduce the observed features at regional scale, particularly over the monsoon region (Kumar, *et al.,* 2002). Several downscaling approaches are being used to derive the regional features from large scale model simulations. Under the projected climate change scenario, India will be one of the Countries facing the adverse impacts of climate change as agriculture is the mainstay of people of India.

Gadgil (1988); Gosami *et al.,* (2006); Guhathakurta and Rajeevan (2006); He Jin-Hai (2009); Krishnamurthy and Shukla (2000); Krishnakumar *et al*., (2008 and 2009); Kumar *et al* ., (2002); Naidu, *et al.,* (1999); Parthasarathy and Dhar (1975); Pant and Hingane (1988); Pai and Rajeevan (2007); Rajeevan (2001); Kumar *et al.,* (1992); Raju *et al.,* (2008); Rao, *et al.,* (2008) and Yin (1949) studied from time to time on rainfall variability across the Country. There was a marginal increase in annual rainfall though not significant. The tele-connections between El Nino and monsoon rainfall have been also brought out. Spatial and temporal variations of rainfall were significant on both daily and seasonal time scales. However, the mechanisms responsible for the intra seasonal variations in rainfall as well as monsoon breaks are not well understood. It was also observed that there was a diminishing trend in annual and monsoon rainfall across the Western Ghats. There was no definite cyclic trend though the trend in one direction reverses its direction after some years. It was also highlighted that the sea surface temperature may modulate the temporal variations of rainfall across the Country. The monthly variations in rainfall revealed that the contribution of June and July rainfall is decreasing while that of August and September is increasing All these studies indicate that rainfall increase was noticed at all India level while such trend was not noticed at regional level. Several regions indicated declining trend in annual rainfall across the Country. This could be attributed to air pollution in terms of minute suspended particulate matter (SPMs) like aerosols, sulphate particles, dust particles, fine sand, and smoke from forest fires, salt particles and pollen in addition to deforestation.

2.3 CLIMATE CHANGE OVER KERALA

2.3.1 Temperature

A clear upward trend in surface air temperature across the West coast between 1961 and 2003 by 0.8°C in maximum and 0.2°C in minimum temperature, with an increase in average surface air temperature of 0.6°C was noticed. According to the India Meteorological Department (IMD) the maximum, minimum temperature and mean temperature over the State has increased by 0.8°C, 0.2°C and 0.5°C respectively during the last 43 years from 1961-2003. Rao *et al.,* (2009b) have reported that there was an increase in maximum temperature over the State by 0.64°C during the period of 49 years, commencing from 1956 to 2004 while the increase min minimum temperature was 0.23°C. Over all increase in annual average temperature was 0.44°C.

2.3.2 Rainfall

Joseph *et al.,* (2004) analyzed time series of daily rainfall of south Kerala using data from a net work of 39 to 44 rain gauge stations for the summer monsoon season of 95 year (1901-1995) to study the inter-annual variation of the period of the intra-seasonal oscillation (ISO). They found that the period of intra-seasonal oscillation does not vary during a monsoon season in most of the years, but it has large inter-annual variability in the range of 23 to 46 days. They also found that of the 95 years, 11 years had no significant ISO. Krishnakumar *et al.,* (2007 and 2009) have observed that monthly rainfall in Kerala during June and July was decreasing while increasing in August and September, indicating that there was a shift in monthly rainfall as August and September rainfall was increasing.

Raj and Azeez (2009 and 2010) reported that annual rainfall in the Palakkad Gap in the Western Ghats shows variation with altitude, revealing that the annual rainfall in the region is comparatively lesser than that of the entire State. A significant decrement in the annual rainfall, winter rainfall and the southwest monsoon was also reported. Nayagam *et al.,* (2008) have attempted to develop a linear multiple regression model for the long range forecasting of monsoonal rainfall of Kerala using ocean and atmospheric parameters as input. Simon and Mohankumar (2004) studied the variation in the occurrence of rainfall using factor analysis and found it significantly influenced by the general physiographic of the State. They also reported that the altitude and rainfall in Kerala are not correlated.

Soman *et al.,* (1988) have reported a fall in the annual rainfall in the southern part of Kerala. However, they could not find similar decrement in the northern part of the State. Singh *et al.,* (1989) studied that inter-annual and long term fluctuations of various rainfall events and reported that for most of the rainfall periods, the time series of starting and ending dates and length are homogeneous and random, and tend to observe the normal probability distribution.

The Precipitation Concentration Index (PCI) series of North Kerala and the annual rainfall series of south Kerala show significantly decreasing trend. Possible changes in the southwest monsoon circulation along the west coast of India and excessive deforestation in Kerala which might have caused these changes. Soman *et al.,* (1988) statistically examined the long terms trends of rainfall of 75 rain recording stations over Kerala for the 80 year period from 1901 to 1980. It revealed that a significant decreasing trend in the rainfall over the eastern high lands and adjacent areas to the west. Ananthakrishnan and Rajan (1987) studied the characteristics of the south-west monsoon rainfall of the low latitudes of Cochin and Minicoy Island using the hyetograms of these stations from 1973-1982. Both station exhibit diurnal variations of rainfall with maximum activity in the post-midnight hours and minimum in the afternoon hours. The amplitude of the diurnal variation increases for rain events of increasing intensities. They also observed that the integrated duration of seasonal rainfall is about 250 h at Cochin and 110 h at Minicoy. Ananthakrishnan *et al.,* (1979) also reported that the pre-monsoon season (March-May) account for several thunderstorm incidences in the State and the winter (December-February) are characterized by minimum clouding and rainfall.

Several workers have attempted to study the date of onset of monsoon. Hsu *et al*., (1999) observed that onset of South China Sea Summer monsoon is the first transition of Asian summer monsoon causing major changes in both convection and winds. Ananthakrishnan and Soman (1988) utilizing the daily rainfall from dense net works of stations, the dates of onset of monsoon over north and south Kerala have been derived on the basis of objective criteria for the years 1901-1980. The mean date of onset for south Kerala is found to be 30 May and for north Kerala 1 June with a standard deviation of 9 days.

The seasonal monsoon transition can occur in a variety of ways with abrupt, gradually or multiple transitions. Though at the surface, the monsoon transitions are first revealed by variability in rainfall, a variety of dynamic and thermodynamic precursors are known to exist (Anathakrishnan and Soman 1991). The onset and dates of the monsoon season can be defined using a wide range of criteria that include rainfall, surface and upper level winds, out going long wave radiation indices, upper troposphere water vapour brightness and temperature. The India Meteorological Department (IMD) has determined the date of onset of monsoon every year for more than 100 years. On an operational mode the date of onset of monsoon is based on the synoptic situations. On real time mode, declaration of the onset date was based on rainfall.

Rajeevan and Dubey (1995) developed a regression model for long range prediction of monsoon onset over Kerala using April mean surface temperature and winter snow cover over Eurasia. Ananthakrishnan *et al., (*1967), Pai and Rajeevan M Nair (2009) developed models to predict the onset of monsoon over Kerala based on the predictors available up to April and May. Several workers viz., Ananthakrishnan *et al.,* (1983); Pearce and Mohanty (1984); Ananthakrishnan and Soman (1988); Soman and Krishnakumar (1993); Joseph *et al.,* (1994 and 2006) reported that large scale changes occur in the circulation features in association with the onset phase of Indian monsoon. Yin (1949) was the first to link the process of monsoon onset to the displacement of westerly troughs in the circumpolar westerlies and shift of the Subtropical Westerly Jet (STJ) to the north of the Himalayan periphery. Koteswaram (1958, 1960) observed that a Tropical Easterly Jet stream (TEJ) also appears over the south India in association with the monsoon onset. Soman and Krishnakumar (1993) studied the climatological features of atmospheric circulation associated with the monsoon onset. Kumar *et al.,* (2004) reported that pre-monsoon rainfall peak exists about seven pentads prior to the onset of monsoon over Kerala.

The satellite derived rainfall estimate has a potential to predict the monsoon onset over Kerala. The correlation coefficient between the observed monsoon onset over Kerala and the estimated monsoon onset over Kerala is 0.72 and is highly statistically significant. Kumar *et al.,* (2008) studied the monsoon onset over Kerala using the high resolution Hamburg Ocean

Atmosphere Parameters and Fluxes from Satellite data (HOAPS 3). Columnar water vapour content, sea surface temperature and evaporation have been utilized to examine the conditions leading to the monsoon onset over Kerala. Sea surface temperature analysis showed that Arabian Sea Warm Pool plays a crucial role in monsoon onset.

Rao and Krishnakumar (2005a) carried out statistical analysis using the long series of data on onset of monsoon and its rainfall over Kerala for the period from 1870 to 2004. It revealed that there was no change in the date of onset of monsoon over a period of time. Pai and Rajeevan (2007) reported that a set of empirical models based on the principal component regression technique was developed for the operational forecasts of the date of monsoon onset over Kerala. Mishra *et al.,* (2004) has attempted to understand the air-sea interaction process before and after the onset of monsoon using a buoy data. Nathan (2000) has reported that the decreasing rainfall over the region, late onset of the monsoon, failure of the monsoon and break in the monsoon in the State lead to many drought situations. Kerala had severe dry spells and droughts in 1983, 1985, 1986 and 1987 even though the State has a wet climate. Pandey *et al.,* (1999) studied the occurrence of droughts and floods over Gujarat and reported that droughts and floods are observed in both arid and humid regions.

2.4 CLIMATE VARIABILITY AND FOOD SECURITY

According the Food and Agricultural Organization (FAO) of the UN, 80 per cent of world rice production comes from ten countries (Table 2.1), out of which the major contribution comes from China and India.

Table 2.1 Top ten rice producing countries of the World

Country	Rice production (Mt) in 2009-10	Percentage contribution
China	166,417,000	32.7
India	132,013,000	26.0
Indonesia	52,078,832	10.2
Bangladesh	38,060,000	7.5
Vietnam	34,518,600	6.8
Thailand	27,000,000	5.3
Myanmar	24,640,000	4.8
Philippines	14,031,000	2.8
Brazil	10,198,900	2.0
Japan	9,740,000	1.9

Parthasarathy *et al.,* (1988) in an unique attempt have developed statistical prediction equation to predict Indian foodgrains production based on Indian summer monsoon rainfall. Roberton (1975) CAgM Rapporteur on meteorological factors in WMO Technical Note No.144 has reviewed the knowledge of the climatological factors defining areas suitable for the production of rain-fed, dry-land rice and to review the present knowledge of the threshold values of the climatological factors which set limits on the profitable production of specified varieties of rain-fed and dry-land rice.

Rao *et al.,* (2001a) reported that excess rainfall throughout the crop growing period during *viruppu* is not conducive and it adversely affects crop yield though rice is a water loving crop. The occurrence of meteorological droughts or dry spell during the reproductive and ripening phases may provide conducive weather, which in turn, will help for better productivity of paddy. However, the occurrence of meteorological droughts or dry spells during June and July delay the transplanting of paddy due to non-availability of standing water. Venkataraman (1987) observed that the major limiting factors for higher productivity are sunshine and temperature. The light and temperature combination play an important role in rice production since the light intensity requirement for rice is higher and temperature dependent.

Takahashi *et al.,* (1955) observed that thermal regime of rice controls the duration of tillering phase of rice. Temperature is an important weather parameter which decides the duration of tillering and tiller production and ultimately the final grain yield of rice. Studies reveal that productivity will decrease as global temperatures increase. Sreenivas *et al.,* (2005) conducted field experiment during *kharif* and *rabi* seasons to study the effect of weather parameters on grain yield of low land rice. The study revealed that the grain yield was positively correlated with accumulated Growing Degree Days (GDD) in reproductive phase during *kharif* and bright sunshine hours during all the three phenophases of rice during *rabi* seasons. They observed that an accumulated GDD of 422°C day and 9.9 hours of daily mean bright sunshine during *kharif* and *rabi* seasons, respectively are required for optimum grain yield of low land rice.

Mathews *et al.,* (1997) reported that simulated yield reduction was 5-7 per cent when mean daily temperature was raised to 1°C. Extremes in temperatures can cause injury to rice plant. High maximum temperature can cause spikelet sterility. Temperatures above 35°C for a few hours at anthesis reduce pollen viability and increases spikelet sterility, which lead to yield loss. Saseendran *et al.,* (2000) have predicted an increase in monsoon seasonal mean surface air temperature of the order of 1.5°C over Kerala in the decade 2040-49 with respect to 1980s. They have conducted temperature sensitivity analysis and shown that for a positive change in temperature up to 5°C, there is a continuous decline in yield. For every one degree centigrade increment, the crop maturity period get decreased by 8 per cent, with consequent decline in yield by 6 per cent. They have also reported that an increase in carbon dioxide concentration leads to yield increase due to its fertilization effect and also enhance the water use efficiency of the paddy.

Studies conducted at IRRI have revealed that for every 1°C rise in temperature, paddy yield declined by 10 per cent. In the projected climate change scenario, temperature rise is being experienced across the State. An increase of temperature by 2°C by 2025 would definitely affect paddy production in Kerala. Warmer nights adversely affect paddy yield. Temperature increase, rising sea levels, and changes in rainfalls and distribution expected as a result of global climate change could lead to substantial modifications in land and water resources for rice cultivation as well as productivity of rice. Impact of climate change on rice production in Kerala will depend on the actual pattern of changes in the different rice-growing regions in the State (Kumary, 2011). Rao *et al*., (2011) have reported that the impact of climate change in the form of climate variability like floods and droughts adversely affected food and plantation crops to a large extent and thus there is an urgent need to adapt crop management, crop improvement and crop protection strategies in tune with projected climate change scenarios so as to mitigate the ill effects of weather aberrations and sustain agricultural production in ensuing decades.

Rao (1999a) highlighted that the grain yield in *kharif 1994* was relatively low due to heavy rains during flowering, led to high percentage of chaffing. Samui (1999) conducted an experiment with four traditional photosensitive varieties and one high yield variety grown during the *kharif* season under rainfed conditions. Using curvilinear technique he found that verities grown in different agro-climatic zones performed differently to climatic parameters. The maximum yield was obtained when the rainfall was between 100 and 115cm. Optimum temperature range was 29-32°C in case of maximum and 23-25°C in case of minimum. The photo-insensitive high yielding variety performed well even at low light intensity (250-350 hrs of bright sun shine). Rao and Subash (1998a) observed that the *kharif* productivity index (KPI) versus the monthly rainfall index (RI) from April to September accounted for 37 per cent variability in *kharif* rice productivity. Takahashi *et al*., (1955) observed that thermal regime of rice controls the duration of tillering phase of rice. Temperature is an important weather parameter which decides the duration of tillering and tiller production and ultimately the final grain yield of rice.

There existed a significant negative correlation between water surplus from June to September and rice yields, thus indicating the overall adverse effects of high water surplus on grain yield of rice. The grain yield of paddy was low whenever the yield moisture index exceeds greater than 85 per cent, indicating potential flood damage and better yield is expected whenever the yield is below 40 per cent (Rao, 1994). Seshu and Cady (1984a) carried out statistical analysis of weather data and yield and developed a regression equation for the relationship between rice yield and temperature. Yadav and Sastri (2006) conducted field experiment to study the relationship between gall midge incidence and rice yield under different sowing dates. It revealed that under late planting conditions and at late vegetative stage, the gall midge damage was more likely. They have developed a regression equation based on the pooled data on different dates of planting and the equation accounted for 90 per cent variation in yield with gall midge incidence during the entire crop growth period.

2.5 CROP WEATHER RELATIONSHIPS

Physiographically, Kerala is divided into three categories- the low land, the midland and the highranges depending upon the elevation from the mean sea level. The crop distributions in these zones are mostly determined by the surface air temperature. In the coastal zones of the State, coconut and rice are the major crops. Cashew, rubber, coconut and cocoa are predominantly cultivated in the midlands. Tea, coffee, cardamom, cocoa and black pepper are the major crops grown across the highlands of the State depending upon thermal distribution. All these crops are thermo- sensitive in nurture as they respond quickly to variations in ambient air temperature. It is more so, in the case of cardamom, tea, coffee and black pepper which are grown across the highranges.

Tea and coffee are known as beverage crops while cardamom and black pepper are popular as “Queen of spices” and “King of spices”, respectively. All the crops are foreign exchange earners to the Country and hence very important to the State’s economy. Cardamom and black pepper are considered as the monopoly crops of the State. Kerala is the second largest producer of coffee in India after Karnataka. Tea is also a unique plantation crop in Kerala, the tea industry is centuries old. Though the plantation crops production is subjected to the vagaries of weather, studies were scanty to understand the effect of climate variability/change on plantation crops production across the highranges of Kerala. The studies carried out Chapter 4, clearly brought out that the magnitude increase in temperature was much higher across the highranges in Kerala when compared to mid and low lands due to increase in deforestation. Therefore, it deserves urgent attention to understand the climate variability/change and its impact on the thermo-sensitive crops viz., cardamom, tea, coffee and black pepper. Hence, an attempt was made to understand the impact of climate variability on these important crops across the highranges of Kerala.

2.5.1 Tea

It is difficult to specify the ideal climate requires for good growth especially with regards to rainfall. Attempts have been made using may species to measure the water lost in transpiration. It is thought that the various species of tea do not have unique transpiration coefficients and there fore it is related to the weather conditions and soil types.

MCCulloch *et al.,* (1965) have reported that shade trees in the tea gardens cause considerable reduction in yield under East African conditions. Barua (1969) observed that tea growing area is spread all over the continents except North America within the latitudinal belt 45°C and 35°S and longitudinal belt of 150°E to 60°W. However, tea cultivated near the equator produces almost the same yield every month, but farther from the equator, winter harvest gradually declines and tea plants experience winter dormancy. He has also revealed that temperature and photoperiod are known to influence winter dormancy in tea.

Barua (1989) has also reported that in north East India, in general, and Assam in particular, tea bush undergoes three to four months of winter dormancy between December and March. Costa *et al.,* (2007) reviewed the key physiological processes responsible for yield determination of tea and discuss how these processes are influenced by genotypic and environment. J Uddin *et al.,* (2005) studies the effect of saturation deficit on the yield of tea during the production period (April-December) in 2003. It was found that the saturation deficit has negative effect o yield of tea (r=-0.77) which was statistically significant. The study also revealed that there exists a positive correlation between saturation deficit and evaporation and found to be statistically significant. At the same time, no significant relationship was found among saturation deficit, rainfall and evaporation.

Baby and Sanjay (2006) conducted an experiment consecutively for two years to study the seasonal occurrence of grey blight of tea caused by *Pestalotia/Pestalotiopsis spp.* It revealed that the occurrence of the disease was recorded throughout the year, but the incidence was high during July to December indicating that temperature around 28°C coupled with moderate rainfall could be conducive to disease development. The results indicated that the crop losses due to the disease could be as high as 17% during peak season.

Burgess and Stephens (2010) have reviewed the key climatic factors affecting tea production and discussed the potential effect of climate change on future production. They have observed the effect of latitude, solar radiation, temperature, photoperiod, plant water potential, saturation vapour pressure deficit, changes in carbon dioxide concentration etc., on tea growth and yield. Current models of tea production suggest that tea production in Kenya and southern Tanzania should be well placed to increased concentrations of CO_2. In southern Malawi, where mean temperatures are higher, further increase in temperature is generally expected to have a negative effect on production. The net effect in both the places will depend on the climatic response of pests.

Mohotti and Lawlor (2002) related the diurnal changes in the rate of photosynthesis of mature tea bushes at high elevations in the field in Sri Lanka in relation to environmental conditions. Interactions between factors regulating photosynthesis in tea are also discussed. Mathews and Stephens (1998) described a model predicting biomass production and water use in tea plantations.

Tripathi, *et al*., (2004) attempted to generate tea yield prediction model using Leaf Area Index (LAI) derived from IRS-IC LISS-III sensor records. LAI measurements were made in the fields and an empirical model was developed to find the suitability of using field LAI for annual tea yields. Field LAI values were related to satellite based LAI estimates. They found a strong relationship with a correlation coefficient of 0.76. Thus satellite based LAI values can be effectively used for tea yield prediction model. Ranganathan and Natesan (1987) developed an equation for agro-climatic potential applicable to South Indian conditions based on growth of tea plant as related to photosynthetic efficiency and weather parameters. A prediction value of 50 per cent was achieved by using agro-climatic potential of the previous month and that of the current month. The rest of the prediction should come from crop husbandry and manuring practices which affect the per cent of total dry matter harvested as crop and availability of minerals.

Pandey (2009) conducted and experiment and demonstrated that biochemical could be used effectively to enhance early bud break in pruned tea bushes and /or reducing the winter dormancy and thereby achieve a higher level of productivity without affecting the quality. Certain chemicals like cycocel when used judiciously can be applied to regulate rush season crop in Northeast India. Squire *et al.,* (1993) studied the shoot production for two clones at four sites in western Kenya differing by 300 m in altitude and 16.4°c to 18.1 °C in mean air temperature. It was observed that the duration of shoot growth cycle increased with altitude and the rate of shoot extension decreased due to temperature differences.

Wijeratne (1996) discusses the various aspects of the adverse effects of climate change on Sri Lanka’s tea industry. He has observed that tea yield is greatly influenced by weather. Drought causes irreparable losses to tea gardens as irrigation is seldom practiced in tea gardens. In the projected climate change scenario, Sri Lanka is likely to experience heavy rainfall events and warmers temperatures. He noted that increase in temperature, soil moisture deficit and saturation vapour pressure deficit in the low elevations will adversely affect growth and yield of tea.

Rao *et al.,* (2008) have opined that the thermo-sensitive crops like cocoa, black pepper, coffee, cardamom and tea may need attention as temperature range is likely to increase and rainfall is likely to decline in addition to deforestation as these crops are grown under the influence of typical forest-agro-ecosystems. Rao, *et al.,* (2009a) while highlighting the climate change/variability studies in the State, have observed that climate variability in the highranges of Kerala is likely to adversely affect the thermo-sensitive crops like tea, coffee, and cardamom, cocoa. Kumar and Kumar (2011) observed that ecological variables are independent and cumulative effect of each variable was found to influence the crop yield significantly.

2.5.2 Coffee

Coffee is a tropical plant which grows between the latitudes of 25 degrees North and 25 degrees south of the equator. Temperature, rainfall, sunlight, wind and soils are all important for the better growth and development, but requirements vary according to the varieties. Ideal average temperatures range between 15 to 24ºC for Arabica coffee and 24 to 30ºC for Robusta which can flourish in hotter, drier conditions but does not tolerate temperatures much below 15ºC, as Arabica can tolerate for short periods.

In general, coffee needs an annual rainfall of 1500 to 3000 mm, with Arabica needing less than other species. The pattern of rainy and dry periods is important for growth, budding and flowering. Rainfall requirements depend on the retention properties of the soil, atmospheric humidity and cloud cover, as well as cultivation practices. Whereas Robusta coffee can be grown between sea-level and about 800 metres, Arabica does best at higher altitudes and is often grown in hilly areas. As altitude relates to temperature, Arabica can be grown at lower levels further from the Equator, until limited by frost.

Kannan *et al*., (1987) have observed that black pepper and coffee behave differently towards the summer rainfall. While the summer rainfall during March/April and April/May are good for coffee it is not favourable for black pepper. Therefore, they have suggested that under the Wayanad conditions a crop mix of coffee and black pepper may be adopted by the farmers. Sunil and Devadas (2009) observed that rains during February and April were favourable for coffee and black pepper. But rains in March adversely affected the black pepper. They also suggested a mixed farming of coffee and black pepper in order to ensure reasonable net return from unit area. Lazarus *et al.,* (2005) studied the yield variations in Panniyur -1 pepper variety and robusta varieties of coffee in relation to rainfall at critical periods.

Marimuthu (2005) carried out a study to evaluate the critical leaf water potential (LWP) for irrigating Robusta and Arabica coffee cultivars. The study revealed that the important physiological activities viz., stomatal conductance, photosynthesis, growth parameters and nutrient absorption, particularly N significantly decreased when irrigation was given at LWP below -15 MPa and -20MPa in Robusta and Cauvery respectively. The study holds good for mature coffee trees as well. Soto *et al.,* (2000) conducted an of-farm research to find out the effect of shade structures on coffee grain yield and assessing the potential use of associated plant species. It showed that shade cover percentage and coffee shrub density had significant effects on yields. But shade tree density had no effect on grain yield. It also revealed that coffee cultivar, age of coffee stand, species richness, shade tree density, basal area, slope and aspect did not have significant effects on coffee yields.

The response of coffee floral buds to different water deficits followed by re-irrigation was investigated by Carlos *et al.,* (1991). According to Coffee Guide (2010) it is generally accepted that climate change will affect both arabica and robusta producers. Rising temperatures are expected to render certain producing areas less suitable or even completely unsuitable for coffee growing, meaning production may have to shift and alternative crops will have to be identified. Incidences of pests and diseases will increase whereas coffee quality is likely to suffer, both factors that may limit the viability of current high quality producers.

2.5.3 Black pepper

Black pepper, the King of spices, is the most important spice crop of India; contributing lions share foreign earnings from the export of spices. The distributions of rainfall, moisture holding capacity of the soil and drainage status of the soil are more important than the total rainfall (Sadanandan, 2000). Black pepper grows successfully between 20° North and 20° South of equator and from sea level to 1500 MSL. It is a plant of humid tropics, requiring 2000-3000 mm of rainfall, tropical temperature and high relative humidity with little variation in day length throughout the year. Black pepper does not tolerate excessive heat and dryness.

Early work of Pepper research Station, Panniyur has shown that the flowering in the Pepper plant is initiated by the application of water equivalent of 70 mm or more of rainfall within a period of three weeks, followed by a dry spell (Anonymous, 1954). According to Menon (1981) and Nalini (1983), a dry spell before flowering is advantageous for better crop production. Nalini (1983) also noted a positive correlation of rainfall with flower bud differentiation process which is started during April-May with the receipt of pre-monsoon showers.

Pillai *et al.,* (1987) have reported that the flowering process in pepper is initiated after the receipt of rainfall equivalent to 70 mm after a dry spell. He has reported that the period required for flower bud to differentiate was 20 days. Studies revealed that rainfall received after a period of stress induces profuse flowering in pepper. Growth of fruit bearing lateral shoots and photosynthetic rate are high during peak monsoon (June-July) in India (Mathai, 1983). Nalini (1983) reported that rainfall was found to be positively correlated with flower bud differentiation. The flower bud differentiation started in the shoots in April-May with the receipt of pre-monsoon showers and reached a peak in June-July, synchronizing with maximum rainfall and vegetative growth in the plagiotropes.

Pillai *et al.,* (1987) compared the rainfall pattern and pepper yields during the two extremely adverse years (1980-81 & 1986-87) with that of a favorable year (1981-82) and observed that during both the adverse years, there was a distinct break in the rainfall during the critical period following flower initiation. Menon (1981) observed that extension growth of plagiotrops started in April-May with the receipt of pre-monsoon showers and continued upto August-September. It was also found that 82.43% of the total annual growth of the fruiting branches was registered in June-July, coinciding with the peak period of the monsoon. Sujatha *et al.,* (2005) reported that no significant correlation was observed between weather parameters studied and yield. However, earliness of summer rains and onset of monsoon showed a positive influence in the earliness of the crop.

Thangaselvabal *et al.,* (2008) has reviewed the different aspects of black pepper cultivation and concluded that the demand for black pepper and its products is getting increased year after year in the world markets. Production is not up to the level to meet demand for export. Present level of productivity in India is very poor due to non-adoption of good agricultural practices. Lazarus *et al.,* (2005) showed that while rainfall and the number of rainy days in the months of February and March were positively related to the yield of robusta coffee, the same were negatively related to the yield of Panniyur -1.

2.5.4 Cardamom

Abraham and Tulasidas (1958) reported on the ecological features of the cardamom growing tracts of south India. It was observed that the natural habitat of cardamom is characterized by heavy rainfall, low to medium temperature and high atmospheric humidity. According to George (1976), dependence on the climatic conditions and deforestation in cardamom growing tracts are the constraints in the production of cardamom. The production of cardamom was limited by the deterioration of ecology (Sundaram, 1977). Kithu (1986) reported that cardamom plant is highly susceptible to even minor variations in climate and environment as such annual production of cardamom in the country fluctuates according to climatic factors prevailing every year. According to Pruthi (1993), cardamom thrives at an elevation of 600-1500 m but the most productive range of elevation is from 1000m - 1800 m.

Raj and Murugan (2000) opined that cardamom is a sensitive plant and any serious disturbance in the environment; especially climatic factors will adversely affect the growth, development and production. Cardamom will not come up well in plains and the shade in coconut garden was insufficient for the crop and the elevation of Vellayani (8°29'N; 76°57'E; 64m amsl) was unsuitable for cardamom cultivation. The study also indicated that cardamom thrives well only under definite moisture, shade and thermal regimes (KAU, 2001). According to Santiago (1967), an average rainfall of 1500 mm - 2500 mm is ideal for cardamom growth and development. Rainfall pattern and yield of cardamom over a period of time revealed that the years of low production were those in which timely rainfall was inadequate and prolonged dry summers prevailed (George, 1976).

Rao and Korikanthimath (1983) revealed that yield of cardamom was influenced more by distribution of monthly rainfall rather than the total rainfall and number of rainy days. They opined that showers during April could not give any clue for predicting yield nor the preceding year's rainfall on the succeeding year's crop and the cardamom yield in Coorg district of Karnataka was better in most of years when the annual rainfall was below 2000 mm. There was a considerable variation in rainfall pattern among different cardamom tracts and it was grown in the area where the annual rainfall ranges from 1500 mm to 4000 mm (Bavappa, 1985).

Korikanthimath (1986) reported that cardamom yield could be increased and mortality rate reduced if cardamom gardens are well maintained with proper adoption of package of practices, as the impact of drought during 1982-83 was the worst on cardamom yield as well as mortality rate under neglected condition. Korikanthimath (1987) studied the rainfall data recorded during the period from 1961 to 1985 at Mercara, Coorg district, Karnataka and its impact on cardamom production. He noticed that the meagre rainfall received from January to April in 1964, 1973, 1974, 1979 and 1983 resulted in lesser crop yields. The unprecedented drought during 1983 caused a great setback on the growth and yield of cardamom in Coorg district and the same trend prevailed in other cardamom growing tracts of India. According to Hegde and Korikanthimath (1996), the higher productivity of cardamom in Gautemala was due to availability of well distributed (Bi-model) rainfall. There is a close relationship between cardamom production and rainfall distribution during summer in which both panicle and flower production in cardamom are more (Rao, 2003).

Korikanthimath and Padmini (1999) opined that due to indiscriminate deforestation, the distribution of rainfall particularly the pre monsoon showers in the Western Ghats was affected though there was not much difference in the total average quantity of rainfall. Khader and Syed (1977) reported that an unfavourable microclimate changes the temperature, which in turn influences the release of N, P and S from organic matter. It also affects nitrification and absorption of P and K by the plants. Cardamom thrives better in the temperature range of 10°C - 35°C. According to Abeysinghe (1980), the monthly maximum temperature varies between 24°C and 27°C while minimum temperature between 14°C and 17°C in cardamom growing tracts of Sri Lanka.

Nanjan *et al*. (1981) reported that maximum and minimum temperature should not be more than 19.5 to 25.0 and 15.5 to 17.5°C, respectively during the period of planting for better establishment of cardamom under Yercaud condition, which is located in shevaroy hill of the Eastern Ghats. Experiments were conducted by Gurumurthy and Hegde (1987), to find out causes of low germination of cardamom seeds in winter season at Regional Research Station, Mudigere (mean maximum temperature 30°C and mean minimum temperature 10°C) and Agricultural Research Station, Ullal (mean maximum temperature 33.7°C and mean minimum temperature 18.8°C). They observed that germination was significantly correlated with minimum and maximum temperature. Korikanthimath *et al*. (1998) reported that the increase in minimum temperature in cardamom growing tracts was due to deforestation, felling and excessive opening of canopy during the last decade.

Cardamom is very sensitive to temperature fluctuations (Jacob *et al.*, 1995). They also revealed that cardamom prefers a mean annual temperature of around 26°C and at high temperature, plants show symptoms of drying out and both growth and yield are considerably reduced. Murugan *et al*. (2000) studied temperature trend in cardamom hills (Kerala) by analyzing 20 years of temperature data. They revealed that minimum temperature exhibited drastic variation over the years and the difference between the warmest and coolest month had narrowed considerably and the days have become warmer markedly. John (2003) reported that the temperature was in the range of 18°C to 24°C in the cardamom tracts of Guatemala. It is understood from the above that the cardamom thrives better in a thermal regime of 14°C – 27°C, reflecting the thermal environment of hills as optimum in the tropics.

2.5.5 Cocoa

Cocoa (*Theobroma cacao* L.), a beverage crop native to Amazon basin of South America, got its entry into India in the early half of the 20th Century. Though it is a native of Amazon region, the bulk of it is produced in the Countries viz., Ivory Coast, Ghana, Indonesia, Nigeria, Cameron, Brazil, Ecuador and Malaysia. Ivory Coast leads in cocoa production in the World with a contribution of 38 per cent, followed by Ghana and Indonesia. It has been introduced in India as profitable mixed crop in coconut and arecanut plantations in 1960s. The crop is now cultivated in an area of 34,049 ha with an annual production of 11,820 tonnes and productivity of 550 kg/ha in India. Comparing this to the global production of 36.49 lakh tonnes, India is no way nearer to the global situation.

Kerala ranked first in production, accounting for 31 per cent of area and 52 per cent of the production in India. Karnataka, Andhra Pradesh and Tamil Nadu are the other cocoa growing states. In Kerala, the crop is now cultivated in an area of 10708 ha with an annual production of 6100 tonnes and productivity of 685 kg/ha. The productivity of cocoa was low (500 Kg/ha) in 2003-04 despite increase in area and no improvement since last five years was seen in terms of cocoa productivity.

Cocoa is a tropical crop grown under equitable climate with well distributed rainfall. It requires an annual rainfall of 1500-2000 mm with a minimum of 90-100 mm rainfall per month. In majority of the regions, where cocoa is cultivated, a high but often unevenly distributed annual rainfall occurs; resulting in fairly well defined dry and wet seasons. These seasonal changes exert marked effects on the growth of cocoa tree, and on its cycle of flushing, flowering and fruiting. Cocoa flowers throughout the year, but significant variation is observed in monthly pattern of flowering, fruit set and bean size. Bhat (1983) reported that a tree produces about 8000 to 10000 flowers per year but only 4 per cent of them set fruits and only 16 per cent of the set fruits matured. The peak period of cocoa flowering varied depending upon the location. It is reported that the peak period of flowering in Ghana, Cuba, South America and India was seen during April-June, June-September, October- May and November-May, respectively (Fig. 2.1). Cocoa flowering and pod set decide the output of cocoa.

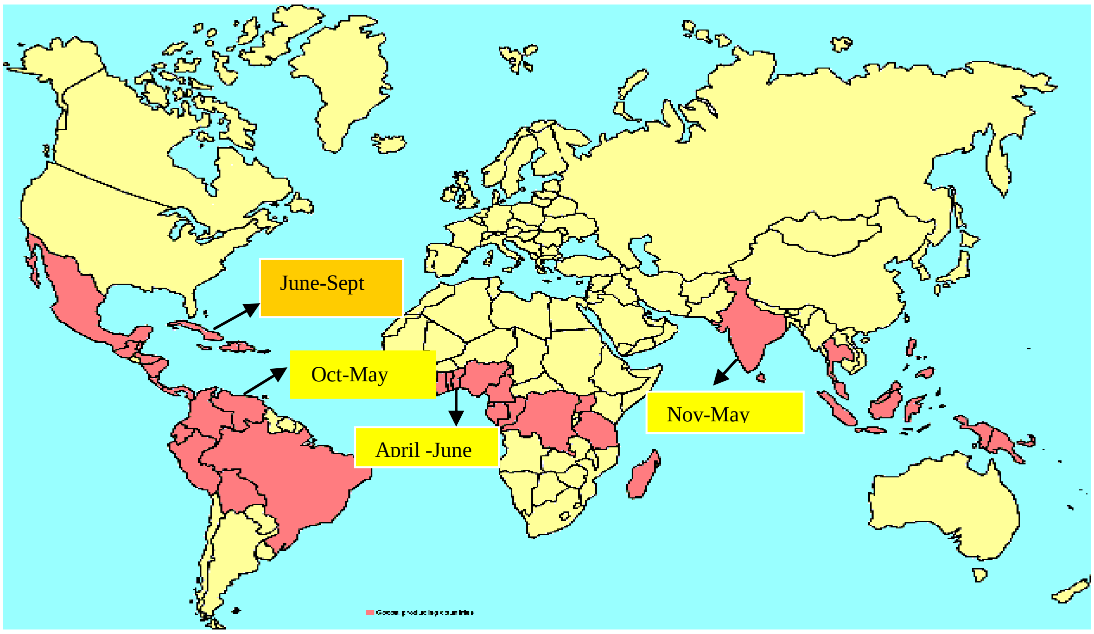


Fig. 2.1 Cocoa growing regions over the world and peak period of flowering

The optimum temperature range for cocoa varies from 21.1°C to 32.2°C, with a mean monthly minimum of 15°C as the lower limit and an absolute minimum of 10°C. However, there is evidence that somewhat lower temperature can be tolerated. It is reported that the humidity above 85 per cent is the optimum for growth. Shade studies on cocoa indicated progressive increase in yield (with the use of chemical fertilizers) and progressive decrease in vegetative growth with decreasing levels of shade (Nair *et al*., 1996).

The climatic conditions of cocoa growing areas vary from one location to another still, they fall in the tropical range. The vegetative and reproductive growth of cocoa is influenced by a complexity of environmental factors, particularly rainfall and temperature. Bhat (1983) recorded 8000-10000 flowers per tree per year out of which only 3.7% of the flowers set fruits and only 16% of the set fruits matured under Dharward conditions. It is also observed that about 70% flowers were produced on the crown periphery, 22% on primary branches and 8% on the trunk. The studies conducted by Nair *et al*. (1996) at the KAU on the response of cocoa to shade indicated that the girth of the stem and yield increased with increase in illumination levels. The results suggested that it is possible to cultivate cocoa without shade under Kerala conditions and that the productivity will be the highest under shade free situations. However, shading may be necessary in the early years using temporary shade plants.

Asopa and Narayanan (1990) described well distributed rainfall above 1200 mm a year as the most conducive for growth. Alvim (1959) reported that where rainfall was adequate and the dry season was not very severe or prolonged, irrigation seemed to have only a small effect on mature cocoa. A highly significant negative correlation is shown between yield and rainfall (Fowler *et al*., 1956, Gordon, 1976). Ali (1969) in Ghana found a positive correlation between yield and rainfall at some times of year and a negative correlation at others. In the case of cocoa, Alvim (1977) reported that seasonal variations in yield are more pronounced in regions where there are marked seasonal variations in climatic factors like rainfall. Correlation coefficients of number of rainy days of previous year (23rd fortnight) found significant with cocoa yield (Vijayakumar *et al*., 1991). In the State of Sao Paulo, cocoa has been planted in places where the mean monthly minimum in the coldest month is about 10^{o} C and the absolute minimum drops to 4^{o}C to 6^{o}C (Alvim, 1977). Lee (1974) reported that in Malawi (13^{o} 3'S and 34^{o}E) where the minimum temperature is 13^{o}C to 14^{o}C for three months, cocoa has been grown successfully giving yields up to 2000 kg/ha, but when the temperature fell to 10^{o}C for several consecutive days yields were reduced by about 50 per cent.

Plants at the low humidity flushed before the others, but thereafter the period between flushes was rather longer at low and medium than at high humidity (Sale, 1970). The optimum range of mean monthly temperature of cocoa growing region is 15-32^{o}C. The absolute minimum temperature for any responsible period should be 10^{o}C, below which frost injury takes place. However, cocoa grows and produces well in plains with more moderate temperature (ICAR, 2002). Murray (1961) working on older trees in Trinidad found irrigation to be beneficial in only one year out of five studied. Clearly, there will be variations in the severity of dry seasons, but in the case of established trees, there may be a long period during which adaptation to a new soil moisture regimes takes place. Container experiments involving watering regimes have generally demonstrated the beneficial effects of wetter treatments on growth (Murray, 1966). In most regions where cocoa is cultivated a high but often unevenly distributed annual rainfall occurs, resulting in fairly well defined dry and wet seasons each year. These seasonal changes exert marked effects on the growth of the cocoa tree, and on its cycle of flushing, flowering and fruiting (Sale, 1970).

The studies conducted by Prameela (1997) showed that the bright sunshine hours had positive influence on flowering and the maximum correlation was noted seven weeks before flowering. The cocoa needs a lot of sunshine with rains for the production of flowers and cherelles. The study revealed that both morning and evening relative humidity had a negative influence on flower production. In both the cases, maximum influence was noted eight weeks prior to flowering. In Karnataka, Jose (1996) compiled the yield data on quarterly basis. It is found that on an average 40% of the fruits was harvested during June to August, 30% between March and May, 16% between September and November and the remaining 14% between December and February. Studies conducted by Amma *et al.* (2005) indicated that a decline of 39% in annual yield was recorded during 2004 due to the disastrous summer drought when compared to 2003. It might be due to a sudden rise in maximum temperature of the order of 2-3^{o}C from 14th January to 16th March 2004 when compared to that of normal maximum surface air temperature (33.0-36.5°C) during the above period. The study also revealed that there was a lag period of four to five months between the occurrence of adverse weather and monthly pod yield of cocoa.

2.5.6 Cashew

Cashew (*Anacardium occidentale L.*) is a very important horticultural crop which fetches considerable foreign exchange to India. The crop is a native of Brazil and was introduced in India by the Portuguese during 16th Century. It is grown in India, Brazil, Vietnam, Tanzania, Mozambique, Indonesia, Sri Lanka and other tropical Asian and African countries. The crop is grown within the latitudinal belt of 27°N and 28°S of the equator experiencing a tropical temperature for its growth and development. The trend in productivity has a phenomenal bearing to the distance from the equator.

The world production of cashew is estimated to be around 20.8 lakh tonnes. The global productivity level is 690 kg/ha. Since 2000, the world raw cashewnut production registered an increase of 40 per cent. India's share in the world raw cashewnut production accounts to about 25 per cent. In recent times, India is facing tight competition from Vietnam and Indonesia in international cashew trade. Since its introduction in the Country, cashew is well adapted to the Indian climatic conditions and is grown in the East and West Coasts of India. Now, India is the largest producer, processor, consumer and exporter of cashew in the World (Bhat, 2009a). In India, cashew is grown mainly in Maharashtra, Goa, Karnataka and Kerala along the West Coast and Tamil Nadu, Andhra Pradesh, Orissa and West Bengal along the East Coast. To a limited extent cashew is cultivated in Gujarat, Manipur, Meghalaya, Tripura, Andaman and Nicobar Islands and Chattisgargh and also in the maidan areas of Karnataka.

India has been exporting cashew kernels since early part of 20th Century. The established processing capacity of raw cashew nuts is around 12-13 lakh tonnes while our domestic production is around 6.65 lakh tonnes only. Thus presently, India is importing raw cashew nuts from African and other countries to meet the demand of cashew processing industries. India has earned an all time high export earnings of 2950 crores during 2008-09 (Bhat *et al.,* 2009b). Studies on 'climate and cashew' in and outside India are scanty. The available literatures on different aspects of cashew with respect to weather have been reviewed.

Hopkins (1938) attempted to express the importance of latitude, longitude and altitude in the distribution and rate of development of plants by means of a "Bioclimatic law". It may be stated as " A biotic event in north America will, in general, show a lag of four days for each degree of latitude, five degree of longitude and 400 feet of altitude, northwards, eastward and upward in spring and early summer". In mango, the India Meteorological Department also established that there was a delay in flowering from south to North of India, which generally followed Hopkins' bio-climatic law (IMD, 1957).

While reviewing the status of cashew research in India, Bhat (2009a) reported that India is the largest producer, processor and consumer and exporter of cashew in the world with a production of accounts to about 25 per cent of to world's raw nut production and is facing tight competition from Vietnam and Brazil in international cashew trade. Bhat *et al*., (2009b) has also reported that India has been exporting cashew kernels since early part of 20th Century. The established processing capacity of raw cashew nuts is around 12-13 lakh tonnes while our domestic production is around 6.65 lakh tonnes only. Thus presently, India is importing raw cashew nuts from African and other countries to meet the demand of cashew processing industries. India has earned an all time high export earnings of 2950 crores during 2008-09. Balasubramaniam (2009) has reported that the trend in productivity of cashew has a phenomenal bearing to the distance from equator. While the productivity is substantially high in areas near to the extremity of specified latitudinal ranges, it narrows down according to the nearing distance to the equator. This may be due to the effect of day length as the sun traverses towards the tropic cancer or towards the tropic of Capricorn. Nambiar (1977) noted that the influence of temperature on growth, flowering and fruiting of cashew is considered more important than relative humidity.

Rao and Gopakumar (1994b) have consolidated the available information on climatic requirements of cashew viz., latitude, latitude and flowering, altitude, temperature, rainfall, relative humidity, sunshine and day length wind, waterlogging and drought and irrigation. They have concluded that the interaction of cashew phenology and its environment in different agro-climatic zones has to be understood clearly for better agro- techniques and agro- technology transfer from potential zones to lower productivity zones which will lead to improved cashew production to a greater extent in adverse weather situation through better agro-techniques. Rao (2002) has extensively studied the crop weather relationships of cashew and concluded that the reproductive phase of cashew is highly sensitive to weather aberrations and final crop yield depends upon weather conditions, provided no pest incidence is noticed. This is one of the reasons for marked variations in the cashew production. Cashew requires relatively dry atmosphere with mild winter for better flowering. Chathopadhayay and Ghosh (1993) have reported that the varietal variation in flowering, time of flower opening and flowering phase is also significant in the case of cashew.

Salam *et al.,* (2003) have developed a model capable of predicting the nut weight of a cashew tree much before harvest, based on canopy radius and number of nuts per square metre taken immediately after nut set and using the weight of a single nut of the variety already determined. The quadratic model developed by them explains the yield variability up to 97 per cent. Sreekanth *et al.,* (2004) attempted to predict cashew yield using explanatory (independent) variables viz., light interception, ground coverage, and plant age under different density of plantings using four regression models viz., linear, logarithmic, power and exponential. The various models developed could obviate the need for cumbersome forecasting models.

Naik *et al.,* (1997) studied the anther and anther dehiscence in cashew and revealed that the staminate and hermaphrodite flowers started opening in early hours of the day and continued till the evening with peak anthesis at 05 30 hrs and 10 30 hrs respectively. Rao and Gopakumar (1999b) studied the latitudinal and altitudinal influence on cashew flowering over Kerala. They have found that there exists a delay in cashew flowering across Kerala depending upon latitude and altitude irrespective of the varietal difference in cashew flowering. The delay in spread of flowering depending upon latitude and altitude across Kerala was 60 days. They have observed that “Bioclimatic law” stated by Hopkins (1938) appears to be sound incase of cashew flowering, if other environmental factors are not limiting. Rao *et al.,* (1999c) revealed that the untimely rains during November and December and rise in night temperature (above 20°C) with less dew nights which coincides with flowering phase in December was detrimental to cashew production by way of altering flower induction.

Ghosh (1999) conducted an experiment on the effect of rain water harvesting on nut yield of cashew. It was reported that the yield increased by 146.7 per cent as compared to control. Rao *et al.,* (2001b) reported that the bud break in cashew followed after heavy wet spell of rains in the presence of bright sunshine depending upon the genotype. They observed that the flowering of cashew required mild winter in humid tropics. In a study to assess the effect of various weather parameters on the performance of mixed population of cashew nut hybrids, Haldankar *et al., (*2002) reported that rainy days showed a significant positive correlation with yield. Rainy days explained the yield variability up to 54 per cent. The relationship between monthly rainy days of May and June with yield was significant where as the rainy days in other months has poor relationship with yield of cashew hybrids. The rainy days in May explained 59 per cent variation in yield followed by June, 50 per cent. Haldanker *et al.,* (2003) also studied the year to year yield variation of the variety Vengurla1. It was observed that maximum temperature, humidity and rainfall jointly determine the yield where as the relative humidity alone showed significant positive association with yield. It also revealed that relative humidity during pre-blooming period play a significant role in explaining yield variation of the variety Vengurla1.

Pushpalatha *et al., (*2005) highlighted the influence of climatic factors on quality of cashew nuts and kernels. Temperature prevailing during flowering, nut set and development is a factor governing the quality of nuts. The hot days have positive effect on nut quality, while high night temperature has negative effect. Cool nights are preferred for good quality nuts and intermittent rainfall and high humidity during the reproductive phase of cashew will be having negative effect on quality of nuts. Jeeva *et al.,* (2005) reported that the nut yield per tree was significantly and positively correlated with maximum temperature and rainfall. A multiple linear regression equation developed by them with yield as dependent variable and max temperature, minimum temperature, relative humidity and rainfall as independent variables explained the yield variation up to 31%.

Gopakumar *et al.,* (2005) reported that cashew yield may be poor if it is exposed to humid weather during the reproductive and flowering phase while it is not so under dry weather conditions. Rao and Gopakumar (2009c) have highlighted the influence of weather on cashew production as it is useful to choose the better cashew growing environments to enhance the area under cashew so as to enhance the cashew productivity vertically and horizontally.

2.5.7 Rubber

The natural habitat of rubber (*Heavea brasiliensis*) is rain forests of the Amazon basin, situated within 5° North and South at altitudes below 200m. The climate of this region is equatorial monsoon type characterized by mean monthly temperature by 25 to 28°C, well distributed rainfall and no marked dry weather. Though it is originated in the Amazon basin, it is now predominantly grown in the tropics where an equatorial monsoon type climate prevails. Regions between 8°N and 10°S which includes Indonesian archipelago, Malaysia, southern part of Sri Lanka and some other Islands, are better suited to rubber cultivation.

The production of natural rubber in the country was 8.65 lakh MT in 2008-09, registering a 4.74 per cent growth compared to the previous year. India is the fourth largest producer of natural rubber with a share of eight per cent in the World after Thailand, Indonesia and Malaysia (Table 2.2) and the fourth largest consumer of natural rubber after China, USA and Japan. Among the rubber growing countries in the World, India occupies a pride place with the top most position in productivity.

Table 2.2 Production of natural rubber in major rubber producing countries in the world

Country	Production (‘000 tonnes)	
	2009	2010*
Thailand	3164	3072
Indonesia	2843	2938
Malaysia	970	1050
India	845	890
Vietnam	750	780
China	647	690
Sri Lanka	148	153
Philippines	102	107
Cambodia	45	63

*Anticipating figures

The productivity of natural rubber (NR) in India in 2009-10 was 1784 Kg/ha. In 1950-51, it was 284 Kg/ha. The growth achieved in terms of the productivity of natural rubber is 628 per cent (Table 2.3). This achievement is rare in comparison with other agricultural and plantation crops.

Table 2.3 Growth in area, production and productivity of NR from 1950-51 to 2009-10 in India

Item	1950-51	2009-10	Growth (% increase)
Area (ha)	74915	686882	917
Production (MT)	15800	931400	5895
Productivity (Kg/ha)	284	1784	628

(*After Mohanan, 2010*)

Kerala accounts for 81 per cent of the area under rubber in the Country. The production of natural rubber in Kerala during the year was 7.83 lakh tonnes indicating a 4.00 per cent increase over the previous year. The increasing trend in productivity continued during 2008-09. It was 1190 Kg/ha in 1998-99, which rose to 1514 Kg during 2008-09. In terms of tapping area, the productivity of natural rubber recorded was 1514 Kg/ha during the year 2008-09**.**

Though the production and productivity of rubber is showing an uptrend since long, the crop production is to a certain extent determined by the weather conditions. Rubber requires an equally distributed monthly rainfall of 125 mm which is equivalent to the potential evapotranspiration loss from the tree under tropical monsoon climates. In the tropical monsoon climate, the potential evapotranspiratrion rate is about 4mm per day (Monteith, 1977). Regional yield fluctuations in south India were related to the soil moisture availability (Rao *et al.,* 1990). By increasing soil moisture availability to the plant by providing irrigation, adopting soil moisture conservation techniques, yield loss can be avoided to some extent (Haridas *et al.,* 1987; Vijay Kumar *et al*., 1988). According to Liyanage *et al.,* (1984), Haridas and Subramaniam (1955) rainfall exceeding 9 to 11 mm per day is not congenial as it hinder harvesting and other operations.

Satheesan (1987) has reviewed the work done in characterizing the radiation climate in rubber plantations in determining the evapotranspiration and canopy photosynthesis. Unlike other plantation crops, overall production of natural rubber does not seem to be influenced by drought of a particular year (Sailajadevi, *et al.*, 2005). Temperature is another environmental factor which influences plant growth. The plant gets affected by extreme temperatures. Mean monthly temperature 20-25°C has been found to be optimum. High temperature conditions result in higher rates of evapotranspiration leading to severe soil moisture stress in the absence of rainfall. High temperatures above 37°C, coupled with soil moisture stress, result to injury to leaf and drying of leaf margins (Chandrasekhar *et al*., 1990 and Vijayakumar *et al.,* 1998). Thermal injury coupled with water deficit results in increased tree loss. In areas experiencing low temperature, the growth rate increases with increase in temperature. Under the projected climate change scenario, rubber production also poses threat.

Chapter 3

Data and Methodology

3.1 CLIMATIC DATA OVER INDIA

Homogeneous Indian monthly surface air temperature data sets for the period from 1901-2003 and the longest instrumental rainfall series of the Indian region for the period from 1901 to 2006 were downloaded from the IITM website (www.tropment.res.in) to evaluate the trends in temperature and rainfall across the Country. Temperature data sets pertaining to India, West Coast of India, East Coast of India, Interior Peninsular India, North East India, North Central India, Western Himalayas of India and North West India regions was used for trend analysis. The annual, decadal and tri-decadal trends were worked out for the country as a whole and for different zones of the country based on the downloaded data. Temperature range (the difference between the maximum and minimum temperature) was worked out using the maximum and minimum temperature. Similarly, rainfall data for All India, Eastern Peninsular India, North Central India, North East India, Northern Mountainous India, North West India, Southern Peninsular India and Western Peninsular India were used for trend analysis. Monthly rainfall trends along with projections for 2020, 2050 and 2080 were also worked out. MS Office Excel, SPSS packages were used for working out trend and statistical evaluation of trends. Mann-Kendall Test was used to find out the statistical significance of the time series data of rainfall and temperature.

The Mann-Kendall non parametric test, as described by Sneyers (1990), was applied to in order to detect trends in rainfall as well temperature. The Mann-Kendal test has been used by several researchers to detect trends in hydrological time series data (Brunetti *et al*., 2000a.b, Serrano *et al*., 1999).

Mann-Kendall Test: Mann-Kendall test basically involves the ranks obtained by each data in the data series. The n time series values (X1, X2, X3, ….., Xn) are replaced by their relative ranks (R1, R2, R3,….., Rn) (starting at 1 for the lowest up to n), (Kundzewicz and Robson, 2000; Chiew and Sirivardena, 2005).

The test statistic S is:

$$S = \sum_{i=1}^{n-1} \left[\sum_{j=i+1}^{n} \operatorname{sgn}(R_j - R_i) \right]$$

where
$$\operatorname{sgn}(x) = 1 \quad \text{for} \quad x > 0$$
$$\operatorname{sgn}(x) = 0 \quad \text{for} \quad x = 0$$
$$\operatorname{sgn}(x) = -1 \quad \text{for} \quad x < 0$$

If the null hypothesis Ho (ie, there is no trend in the data set) is true, then S is approximately normally distributed with:

$\mu = 0$

$\sigma = n\,(n - 1)\,(2n + 5)\,/\,18$

The z-statistic is therefore (critical test statistic values for various significance levels can be obtained from normal probability tables):

$z = |\,S\,| / \sigma^{0.5}$

A positive value of S indicates that there is an increasing trend and vice versa.

3.2 CLIMATIC DATA OVER KERALA

Monthly rainfall data for the period from 1871 to 2008 were downloaded from the website www.tropmet.res.in to work out annual, decadal, and tri-decadal trends in rainfall over the State of Kerala. The monthly maximum and minimum temperatures recorded by the India Meteorological Department (IMD) were collected from the National Data centre, IMD, Pune for the available period as given below in table. In addition to the temperature data from the IMD, temperature data from Kerala Agricultural University Research Stations viz., Pattambi, Pilicode, Vellanikkara, Ambalavayal and Pampadumpara were also collected.

Name of IMD Stations	Data period
Thiruvanthapuram	1901-2009
Kozhikode	1901-2009
Kannur	1980-2009
Palakkad	1943-2000
Alappuzha	1944-2009
Kochi	1951-2009
Punalur	1956-2009
Kottayam	1973-2009
Name of KAU Stations	Data period
Pattambi	1950-2008
Pilicode	1983-2008
Vellanikkara	1980-2009
Ambalavayal	1984-2008
Pampadumpara	1978-2009

The above stations were grouped in to coastal, midland and highranges. The station considered for coastal tracts were: Thiruvananthapuram, Kozhikode, Kannur, Alappuzha and Kochi. Stations considered under midlands were: Kottayam, Punalur, Palakkad and Pattambi. Pampadumpara (Idukki) and Ambalavayal (Wayanad) stations were considered under highranges. Statistical significance test was carried out to understand the statistical significance of the trend using the Mann-Kendall Test as described earlier.

Date of onset of monsoon for the period from 1870 to 2010 was collected from the records maintained at the Academy of Climate Change Education and Research (ACCER), Kerala Agricultural University. Moving averages were worked. Statistical significance was tested. Mean, Standard Deviations and Coefficient of Variations were also worked out. Based on the standard deviation, a year was categorized as early onset year, if the monsoon onset is on or before 25th May and as late onset year if the monsoon onset in a year is after 8th June.

3.3 RAINFALL

The climatological data were pooled season-wise as per IMD classification and are given below:

Season	Period
Southwest monsoon	June - September
Post monsoon	October - November
Winter	December - February
Summer	March - May

The mean monthly, seasonal and annual rainfall for the State was computed to understand the spatial distribution of rainfall. The standard deviation and coefficient of variation of rainfall for different periods were also worked out to explain the variability of rainfall. To understand the location specific trends, rainfall data for the selected stations have been collected from the India Meteorological Department and from KAU research stations.

The monthly rainfall records for each station were arranged in decreasing order and each record assigned ranking number 'm'. Each and every ranking number has a probability level Fa (m) which can be expressed as

Fa (m) = 100 m / n+1

Where n = number of records

The rank number that has the probability level of 75 per cent was calculated. The rainfall record corresponding to this rank number gave the dependable rainfall.

3.4 POTENTIAL EVAPOTRANSPIRATION (PE)

The concept of Potential evapotranspiration was put forwarded by Thornthwaite (1948) and it is widely accepted and utilized in various fields such as delineation of climatic zones, calculation of crop growing seasons and irrigation scheduling based on water balance approach. The potential evapotranspiration is defined as the evaporation from a large vegetation covered land surface with adequate soil moisture at all times. The advantage of Thornthwaite's method is that PE can be estimated if mean temperature data is available. It also gives good estimates in coastal states where mild winter is noticed and the monthly temperature range is not very large. Because of the simplicity of the method, Thornthwaite's method was used in this study.

Thornthwaite considered temperature and possible number of sunshine hours for the estimation of potential evapotranspiration. The formula given by Thornthwaite for unadjusted PE (e) is as follows:

$E = 1.6\ (10t/I)^{a}$

Where e = monthly unadjusted PE in cm/month

t = Mean monthly temperature in °C

I = Annual heat index $\left(\sum_{I=1}^{12} I \right)$,

I= Monthly heat index and is equal to $(t / 5)^{1.514}$

and a = non linear function of the heat index , approximated expression,

$a = 0.000000675\ I^3 - 0.0000771\ I^2 + 1.7921\ I + 0.49239$

The unadjusted PE (e) so obtained is for average 12 hours of sunshine and 30 day month. The values can be adjusted by multiplying with a correction factor depending on the latitude and season

3.5 WATER BALANCE STUDIES

The water balance elements viz., precipitation, potential evapotranspiration (PE), actual evapotranspiration (AE), water surplus (WS) and water deficit (WD) were computed by the revised book-keeping procedure of Thornthwaite and Mather (1955). For the evaluation of the complete water balance of a station, it is necessary to compare precipitation (water supply) with potential evapotranspiration (water need) making allowance for the storage of water in the soil and its subsequent utilization for evapotranspirational purposes.

Water balance indices such as humidity index (I_h) and aridity index (I_a), the index of moisture adequacy (I_{ma}) and moisture index (I_m) were calculated making use of the following formulae:

1. Humidity index I_h = WS/PE X100
2. Aridity index I_a = WD/PE X100
3. Index of Moisture Adequacy I_{ma} = AE / PE X 100
4. Moisture Index I_m = I_h - I_a

The water balance elements and climatic indices so obtained for the State were presented and discussed. Climatological droughts and climate shifts were also worked out.

Climatic shifts were worked out using the water balance and climatic type identified based on the moisture index values given in the Table below:

Climate classification	Climate type	Moisture index (Im) in %
E	Arid	-40 and below
D	Semiarid	-39 to -20
C1	Dry subhumid	-19 to 0
C_2	Moist subhumid	0-20
B_1	humid	20-40
B_2	humid	40-60
B_3	humid	60-80
B_4	humid	80-100
A	Perhumid	Above 100

Intensity of droughts were worked out as per the procedure given by Subrahmanyam and Subramaniam (1964) and later modified by Subrahmanyam and Sastri, (1971). It is classified on the basis of the percentage departure of aridity index from the median as Moderate, Large, Severe and Disastrous according to the following scheme.

Departure of aridity index (Ia) from the median	Drought intensity
<1/2σ	Moderate
1/2σ to σ	Large
σ to 2σ	Severe
>2σ	Disastrous

Where σ the standard deviation

3.6 CLIMATE VARIABILITY AND FOOD SECURITY

Data on Indian foodgrains production from 1950 - 51 to 2009 -10 along with drought years were collected from the published reports to understand the effect of drought on all India fodgrains production. The rate of percentage increase in foodgrains on pentad basis was worked out to understand the effect of drought. Projections in maximum temperature, minimum temperature, mean temperature and temperature range were worked out for 2020, 2050 and 2080 to understand the impact of increased temperature on Indian foodgrains production.

Area, production and productivity of paddy in Kerala was collected from the Directorate of Economics and Statistics, Govt. of Kerala for the period from 1952-53 to 2009-10 to understand the trend in annual, decadal, tri-decadal area , production and productivity.

Heavy rainfall years were identified to understand the effect of heavy rainfall on paddy production and productivity in Kerala. A year was termed as a heavy rainfall year if the rainfall departure was more than 25 per cent of the long period average (LPA). Rate of increase in paddy production was also worked out to understand the adverse impact of floods.

To understand the impact of unusual summer showers on paddy yield during March 2008, daily rainfall data from Mancombu (Alappuzha District) and Thrissur were collected and presented. Erratic behaviour of monsoon in 2009 led to severe drought like situations in southern districts. Weekly cumulative rainfall data from Kollam and Thiruvananthapuram districts were collected from India Meteorological Department, Thiruvananthapuram and presented to understand the effect of erratic monsoon and its impact on paddy. Prolonged rainfall during 2010 adversely affected paddy farmers. Daily rainfall distribution of Mancombu (Alappuzha district), Kumarakom (Kottayam district) and Thrissur are presented as case studies.

3.7 CLIMATE VARIABILITY AND PLANTATIONS ACROSS THE HIGHRANGES

Rainfall for the period from 1960 to 2009 and temperature data for the period from 1977 to 2009 were collected from Pampadumpara (Idukki district) and rainfall for the period from 1984 to 2008 and temperature for the period from 1984 to 2008 were collected from Ambalavayal (Wayanad district) to understand the rainfall and thermal regimes of plantation crops grown across the highranges of Kerala. Trends in annual as seasonal rainfall and temperature were worked out. Mean temperature and temperature range (the difference between the day maximum and night minimum temperature) was also worked out. Moisture regimes across the highranges and its decadal and tri-decadal trends were attempted to understand the climate shifts across the highranges.

Area, production and productivity data of the selected crops viz., cardamom, tea, coffee and black pepper were collected from the Directorate for Economics and Statistics, Govt. of Kerala, Thiruvananthapuram for the period from 1952-53 to 2008-09 to understand the annual, decadal and tri-decadal trends in area, production and productivity. The decadal and tri-decadal trends in annul rainfall, aridity index, moisture index, number of droughts, temperatures (maximum, minimum, mean and temperature range) were worked out to find out the impact of climate change /variability on plantation crops production, if any.

In the case of coffee and black pepper, yield data for the period from 1976 to 1985 and 2000 to 2008 were collected from the Regional Agricultural Research Station, Ambalavayal to understand the effect of blossom and backing showers on coffee. To work out the relationship between cardamom yield and water deficit, yield data of Cardamom Research Station, Pampadumpara was collected and analysed. Water deficit of the highranges were worked out using water balance procedure to understand the relationship between water deficit and yield of plantation crops. The relationship between the yield of plantation crops and heat unit was evaluated using graphical technique.

Heat Unit (Growing Degree Days) were worked out using the equation

GDD = T maximum + T Minimum /2 – T base

(Where TMax is the maximum temperature °C, Tmin is the minimum temperature in °C and Tb is the base temperature below which no growth takes place. Tb is taken as 13°C in the case of these crops.

3.8 COCOA

. The annual cocoa yield data over the State of Kerala was also collected from the Directorate of Cashewnut and Cocoa Development (DCCD), Govt. of India, Kochi for the period from 1982-83 to 2008-09. Decadal trend in area, production and productivity of cocoa was worked out. Rainfall and temperature for the above period were also collected and agro-climatic analysis was carried out. The yearly yield data of the CCRP (Cadbury-KAU Co-operative Cocoa Research Project) farm and the State were analyzed.

The monthly cocoa yield of the Cadbury - KAU Co-operative Cocoa Research Project farm were collected for 100 trees from 1991 to 2007 and analysed. The weather data for the above period was also collected from the weather data records maintained by the Academy of Climate Change Education and Research (ACCER), Kerala Agricultural University Vellanikkara for the period from 1983 to 2009 and pooled according to the yield data

Soil moisture data collected and maintained by the India Meteorological Department at SMO (Soil Moisture Observatory) Vellanikkara was used to understand the relationship between cocoa yield and soil moisture at 30 cm depth. The routine soil moisture observations are being taken at 10 cm, 15 cm, 30 cm and 45 cm depth.

3.9 CASHEW

Weekly rainfall and pan evaporation data were collected from Regional Agricultural Research Station, Pilicode, Kasaragod district (12°12'N, 75° 10'E) to understand the cashew growing environment (rainfall - pan evaporation) across the cashew growing tract of Kerala. Area, production and productivity data in respect of the country were collected from Directorate of Cashewnut and Cocoa Development, Kochi for the period from 1993-94 to 2008-09 and analyzed. Area, production and productivity of cashew in Kerala were collected from the Directorate of Economics and Statistics, Govt. of Kerala for the period from 1952-53 to 2008-09. Based on this data, trends in area, production and productivity on annual, decadal and tri-decadal basis were worked out.

Rainfall and thermal regimes of cashew have been worked out using the rainfall and temperature data in respect of the midlands of Kerala where the crop is predominantly grown. Meteorological and yield data from various cashew research stations viz., Vengurla (Maharashtra), Madakkathara (Kerala), Chinthamani (Karnataka), Bhubaneswar (Orissa) and Vriddhachalam (Tamil Nadu) were collected to understand the effect of drought on cashew production. Wind data collected from the

Agrometeorological Observatory and maintained by the Academy of Climate change Education and Research, Kerala Agricultural University, Vellanikkara for the period from 1983 to 2009 formed the material for studying the effect of wind speed on cashew flowering.

3.10 RUBBER

Data on area, production and productivity of rubber was collected from the Directorate of Economics and Statistics, Govt. of Kerala to understand the trend in annual, decadal and tri-decadal area, production and productivity. Rainfall regimes for South Kerala was worked out using the rainfall data of Kerala while the data for north Kerala was used to find out the rainfall regime of north Kerala, where rubber is grown. Thermal regimes of rubber were worked out using the temperature data of the midlands of Kerala. Annual, decadal, tri-decadal area, production and productivity were also worked out using the crop data. Trends in rainfall, moisture index, aridity index, number of droughts and trends in temperature were worked out to find out the relationship between climate change and yield, if any.

Chapter 4

Regional Climate Change

Climate projections indicate that the increase in temperature over the country is likely to be around 3°C by 2100AD. It will impact the Agricultural sector adversely and the crop losses will be felt much more after 2050 with increase in CO_2 and temperature. The coastal belt of the country is under threat due to sea level rise and as a whole, the food security is in threat due to global warming and climate variability / change. The present updated information also confirms the above findings, which is as follows:

4.1 TEMPERATURE TRENDS OVER INDIA

The increase in annual maximum temperature was 0.76°C while 0.22°C in the case of minimum temperature. The increase in annual mean temperature was 0.49°C while 0.54°C in the case of temperature ranges (Fig. 4.1). The above trends were statistically significant at 1% level. All the months showed warming trends though the trend in night temperature declined in half of the months (Jan, May, June, July, August and September).

The rate of increase in temperature (Fig. 4.2) is relatively high in post monsoon (0.0103°C per year), followed by winter (0.0099°C per year) in the case of maximum temperature**.** Such trend was not noticed in the case of temperature range. It is a concern in northern States during *rabi* season as the winter crops are adversely affected due to temperature increase. It is more so in the case of wheat and temperate fruit crops.

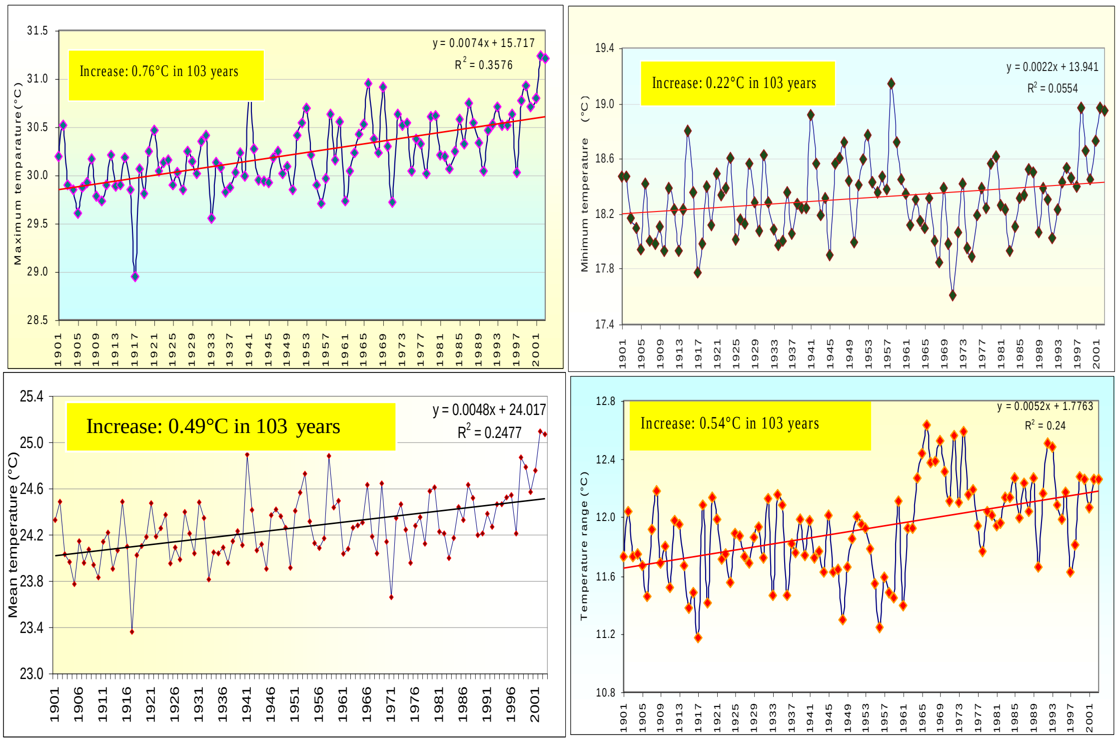


Fig. 4.1 Temperature trends over India

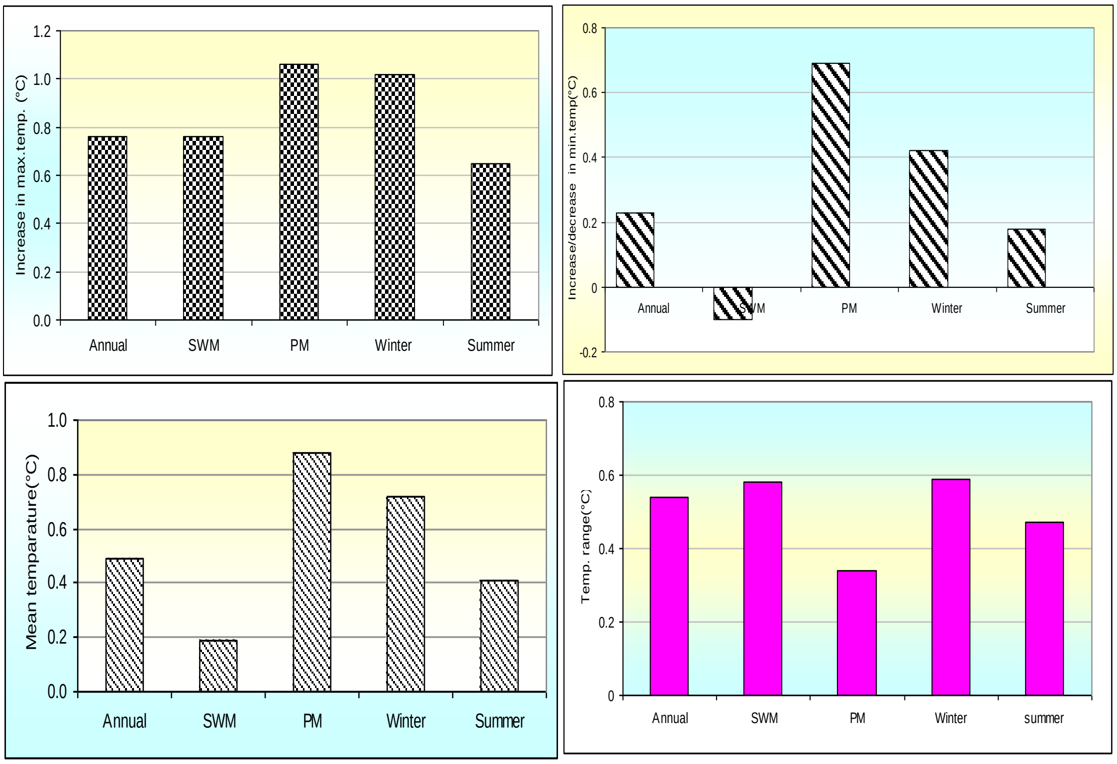


Fig. 4.2 Annual and seasonal temperature- rate of increase in maximum, minimum, mean and range (°C) over India

The rate of increase in maximum, mean and range of temperatures was relatively high across the West Coast of India when compared to that of other zones. It was not so in the case of minimum temperature as the Western Himalayas of India recorded high minimum temperature when compared to that of other zones across the Country (Fig. 4.3).

(WCI-West Coast of India; ECI-East Coast of India; IPI-Interior Peninsular India; NEI-North East India; NCI-North Central India; WHI-Western Himalayas of India; NW-North West India)

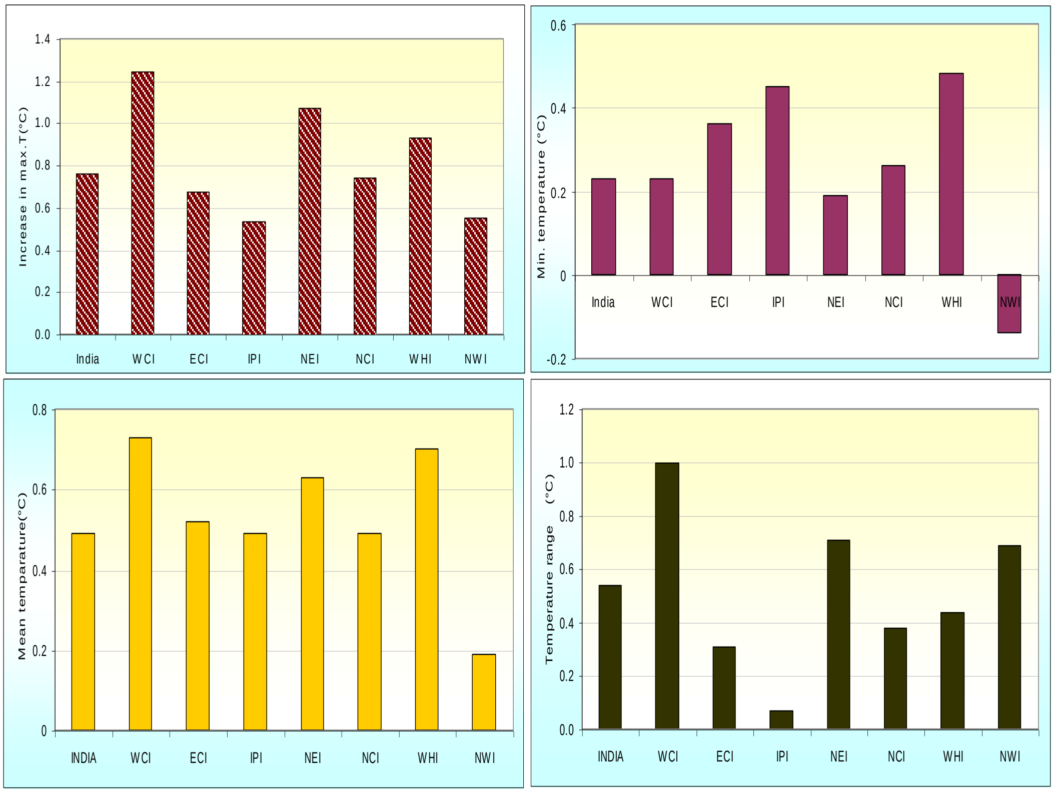


Fig.4.3 Rate of increase in annual maximum, minimum, mean and temperature range (°C) across different zones of India

Increase in temperature might be one of the reasons for glacier melt across the Himalayas. It is again a concern and threat to the two rich hotspots of biodiversity in the Country as the rate of increase in temperature is relatively high across the Western Ghats and Western Himalayas of India.

4.2 TEMPERATURE PROJECTIONS

The projected annual maximum temperature from the base period of 1961-90 assuming a linear trend would be 0.9°C, 1.9°C and 2.8°C by 2020, 2050 and 2080 AD, respectively at the current rate of increase. It was 0.7°C, 1.4°C and 2.1°C in the case of minimum temperature by 2020, 2050 and 2080 AD, receptively. The rate of increase in mean temperature is similar to that of minimum temperature (Fig.4.4). Of course, the rate of increase in ensuing decades may vary depending upon the emission of greenhouse gases, in particular the emission of CO_2 as it accounts up to 70-75% of increase in atmospheric temperature.

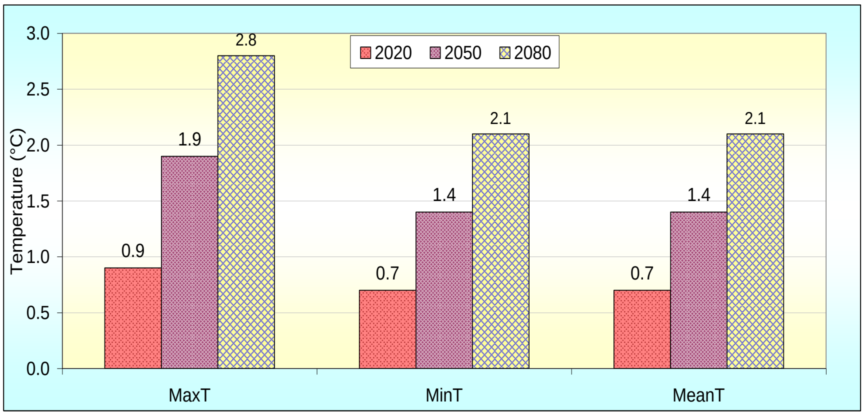


Fig. 4.4 Projections in rate of increase in temperatures across the Country by 2020, 2050 and 2080

The temperature increase is likely to be 0.8-2.4°C by 2080 / 2100 AD if the CO_2 level in the atmosphere is 400 ppm while it is 1.0 - 3.1°C if the CO_2 level is 450 ppm. The temperature increase is abnormally high of the order of 1.5 - 4.4°C if the CO_2 level in the atmosphere is 550 ppm (Fig. 4.5). The present study confirms with the current level of increase in CO_2.

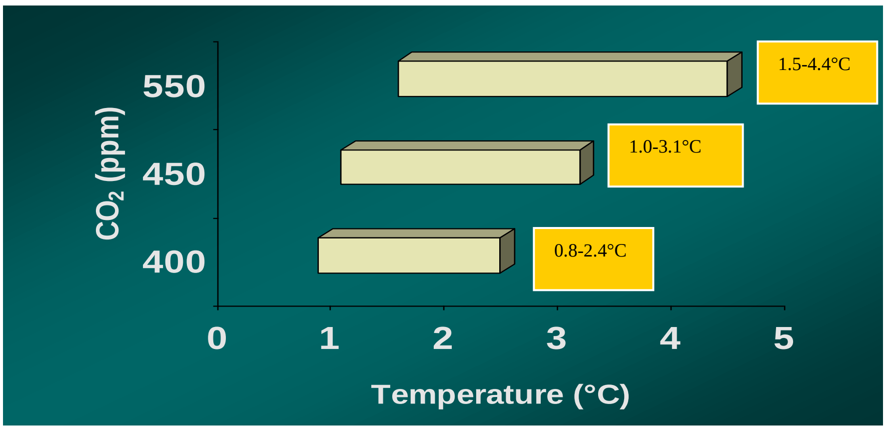
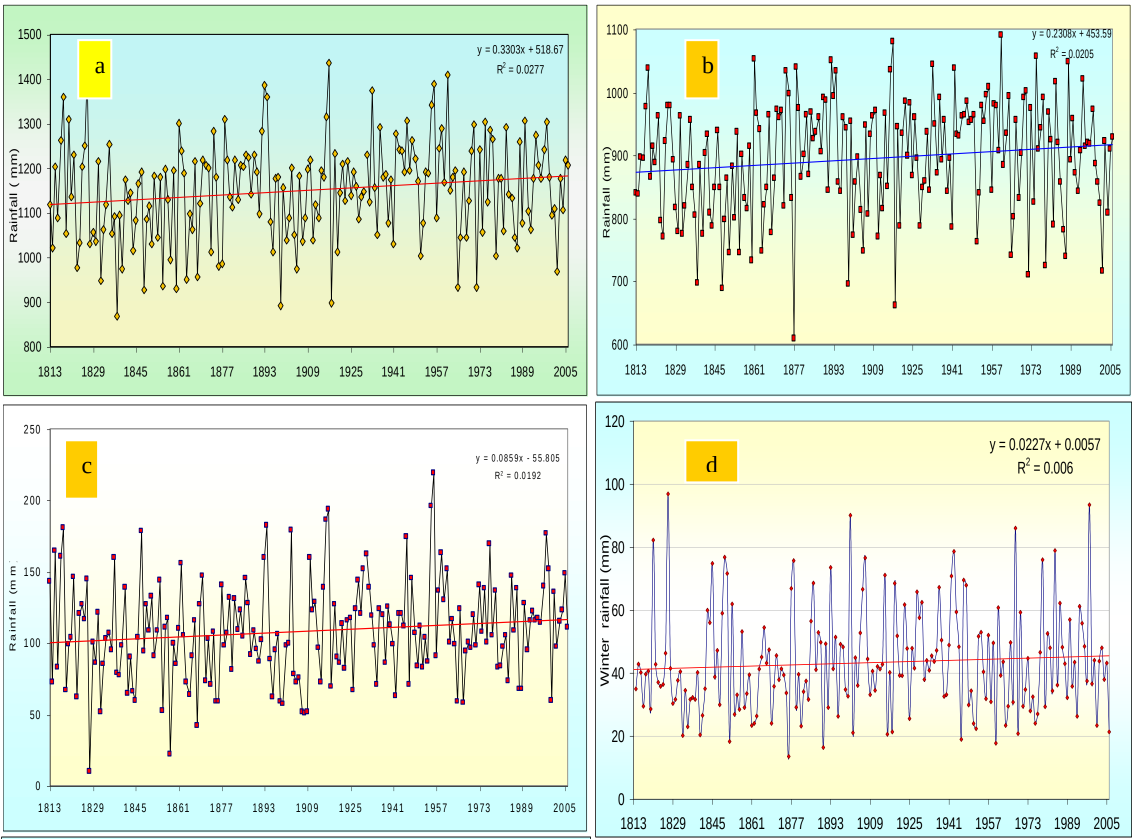


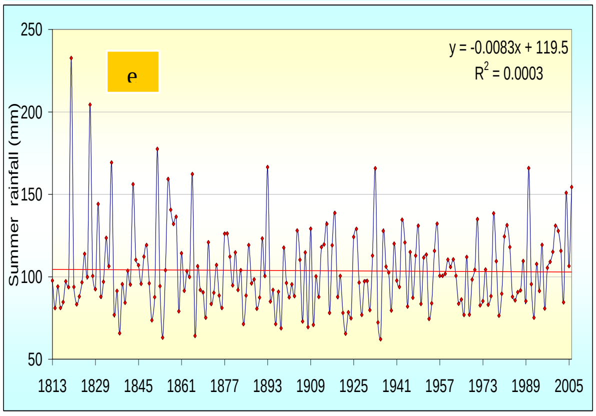
Fig.4.5 Projected CO_2 versus temperature rise (IPCC, 2006)

4.3 RAINFALL TRENDS OVER INDIA

The present study on annual rainfall over the country showed a marginal increasing trend, which is significant at 5% level. The increase in annual rainfall was evident in 1871-1900 and 1931-60. Similar rainfall trends (increase) was noticed in all the seasons viz., southwest monsoon, post monsoon and winter except in summer during which a marginal decline in annual rainfall was noticed (Fig. 4.6). Southwest monsoon rainfall over the Country was significant at 5% level while the post monsoon rainfall was significant at 10% level. Summer and winter rainfall trends did not show any statistical significance. However, the trend in annual and southwest monsoon rainfall was declining since 1960 onwards. At the same time, the annual rainfall was increasing in recent decades during post monsoon season. The monthly rainfall also indicated that there was a decline in June while increase in July, August and September during the monsoon season. Such trend was not seen in all the zones studied where rainfall trends differ spatially and temporally. Rainfall trends were uncertain when compared to temperature trends across the Country.

Rainfall trends were uncertain depending upon the time period and season unlike in the case of temperature. However, the annual and monsoon rainfall for the Country as a whole showed declining trend since last 50-60 years though overall increase was seen during the study period of 194 years. The warming at the regional scale (for the country as a whole) is real and the rate of increase is high (0.0074°C/year) in the case of maximum temperature. On the seasonal basis, the rate of increase in temperature is high during the post monsoon season (0.0103°C/year), followed by winter (0.0099°C/year).





a- Annual; b-Southwest monsoon; c-Post monsoon; d-Winter; e- Summer

Fig.4.6 Trends in annual, SWM, PM, Winter and Summer rainfall (mm) over India from 1813 to 2006

It is inferred from the studies conducted around the world that global average temperature has increased by 0.74°C during the past 100 years due to global warming while the increase in average temperature over India is 0.49°C for the period from 1901 to 2003. It has increased 0.51°C by 2005. Recent studies indicated that the increase in average temperature is 0.61 based on the data from 1901 to 2009. It is likely to increase further depending up on the emission of GHGs in the atmosphere. The increase in maximum temperature across India is 0.76°C during the period from 1901 to 2003. Over India, temperatures are increasing. Most of the warming over

India is due to increase in maximum temperatures. However, during the recent years, minimum temperatures showed some rapid warming suggesting an influence of increase in greenhouse gases. Global precipitation pattern are also changing spatially and temporally. In India also, uncertainties are more in the case of rainfall unlike that of temperature.

Studies indicate reduction of annual rainfall over some parts of the Country while increase in some other parts. In this contest, it is relevant to look into the climate variability/change scenarios in Kerala as it will throw light to take up impact of climate variability with reference to plantation crops, which is one of the objectives of the present study. The trends in temperature and rainfall scenarios over the State have been examined zone-wise viz., coastal, midlands and highranges. Climate shifts and occurrence of climatological droughts have also been worked out to understand climate shifts across the State.

4.4 MAXIMUM TEMPERATURE TRENDS ACROSS KERALA

The maximum temperature over Kerala from 1956 to 2009 showed an increasing trend of 0.72°C (Fig.4.7). The increase was at the rate of 0.01°C per year. It is statistically significant at 1% level. The maximum temperature increased from 31.0°C in 1956 to 32.3°C in 2009. The maximum temperature was the highest (32.8°C) in 1987 and the lowest (31.0°C) in 1956.

The decadal trend in maximum temperature also indicated that the increase (0.4°C) was sharp in the decade 1981-90. Increase in maximum temperature was marginal till 1980. The warmest decades in the State of Kerala were 1981-90 and 2001-09. Both the decades recorded the maximum temperature of 32.0°C each (Fig. 4.8), followed by 1991-2000 (31.9°C).

4.4.1 Coastal zone (Lowlands)

The maximum temperature over the coastal regions of Kerala from 1956 to 2009 showed an increase of 1.09°C (Fig.4.7). The rate of increase was 0.02°C per year and is statistically significant at 1% level. It is evident that the increase in maximum temperature was high (1.09°C) across the coastal belt of Kerala when compared to that of the State as a whole (0.72°C). The maximum temperature increased from 30.3°C in 1956 to 32.1°C in 2009. The highest maximum temperature (32.1°C) was recorded in 1987 and the lowest (30.3°C) in 1956 and 1975.

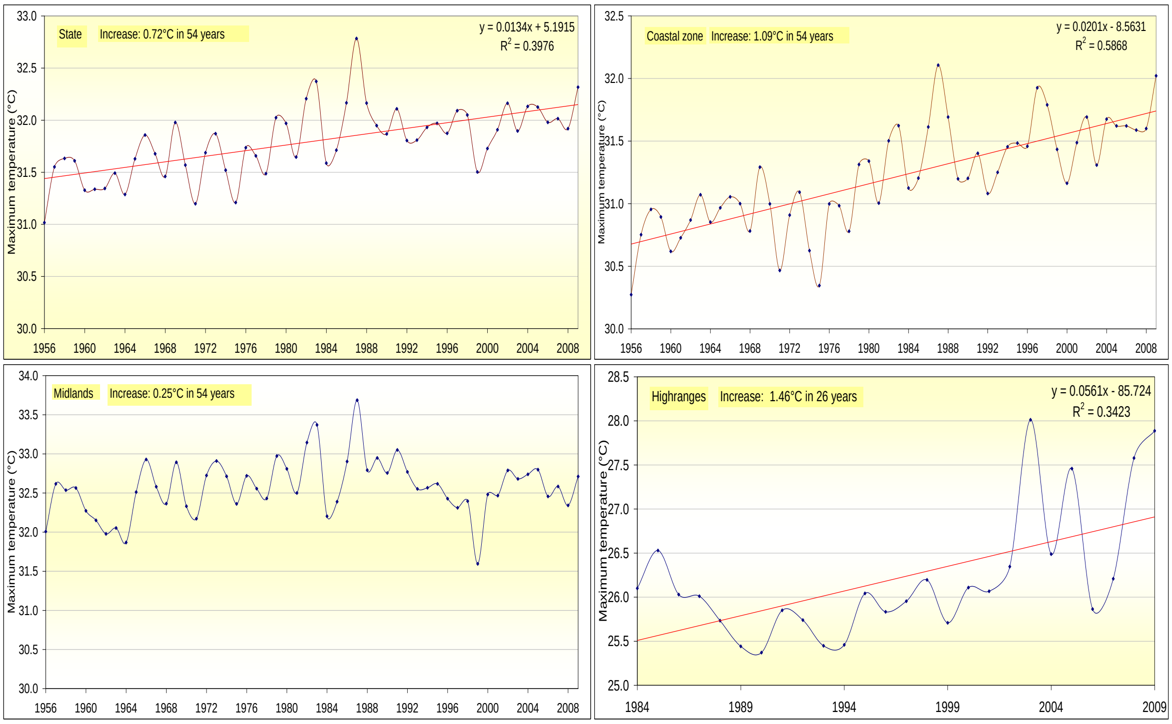


Fig. 4.7 Trends in maximum temperature across the State and at different zones

The decadal trend in maximum temperature also indicated that the increase was sharp from 1981-90 onwards, indicating that the warming of coastal belt of Kerala was felt much more from 1981 onwards. Increase in maximum temperature was marginal in the State till 1980 (Fig.4.8). The warmest decades across the coastal zone in the State of Kerala was 2001-09 (31.6°C).

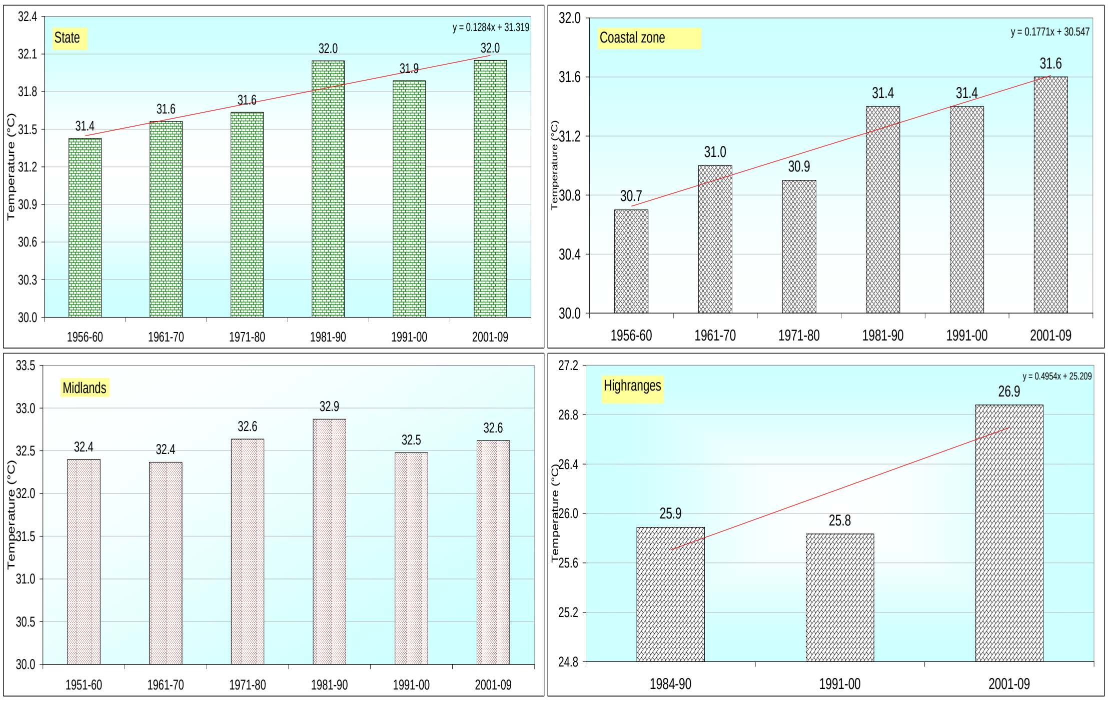


Fig.4.8 Decadal trends in maximum temperature across the State and at different zones

4.4.2 Midlands

The maximum temperature over the midlands of Kerala from 1956 to 2009 showed an increase of 0.25°C (Fig.4.7). It was at the rate of 0.0046°C per year and statistically not significant unlike in coastal belt. The maximum temperature across the midlands of Kerala has increased from 32.0°C in 1956 to 32.7°C in 2009. The highest maximum temperature (33.7°C) was recorded in 1987 while the lowest (31.6°C) in 1999.

The decadal trend in temperature indicated that the increase was dominant in 1981-90 (32.9°C). It was followed by 1971-80 and 2001-09 which recorded 32.6°C each (Fig.4.8). The decade 1981-90 was the warmest and driest decade in Kerala which witnessed for very hot summer in 1987 and unprecedented summer drought in 1983. The increase in maximum temperature was marginal across the midlands of Kerala when compared to that of coastal stations.

4.4.3 Highranges

Since there is no IMD station to record temperature over the highranges of Kerala, temperature data recorded at the Regional Agricultural Research Station, Ambalavayal (Wayanad district) and Cardamom Research Station at Pampadumpara (Idukki district) under the Kerala Agricultural University were utilized for the study. It revealed that the maximum temperature over the highranges of Kerala has increased by 1.46°C from 1984 to 2009 (Fig. 4.7) which is statistically significant at 1% level. The highest maximum temperature was recorded in 2003 (28.0°C) while the lowest in 1989, 1990 and 1993 (25.4°C each).

The decadal analysis reveled that the maximum temperature has increased significantly from 1984-90 (25.9°C) to 2001-09 (26.9°C). An increase of 1.0°C has been registered (Fig.4.8). The increase is significantly felt in the recent decade. It reveals that the effect of global warming and deforestation is felt more across the highranges of Kerala situated in the Western Ghats, one of the hot spot areas of bio-diversity.

4.5. MINIMUM TEMPERATURE TRENDS ACROSS THE STATE

The minimum temperature over Kerala from 1956 to 2009 showed an increase of 0.22°C (Fig.4.9). The rate of increase was 0.004°C per year, which is not statistically significant. The minimum temperature increased from 22.9°C in 1956 to 23.6°C in 2009. The highest minimum temperature

(24.0°C) was recorded in 1983 and 1998 while the lowest in 1974 (22.8°C).

The decadal trend indicated a marginal increase. The rate of increase was 0.03°C per decade (Fig. 4.10). The warmest decade was 1981-90 during which the minimum temperature was 23.5°C. It indicated that the increase in minimum temperature over Kerala was felt much from 1981 onwards, like in the case of maximum temperature. In fact, the minimum temperature before 1980s showed a declining tendency. The warm nights were predominant since last three decades. In fact, the winter 2009-10 recorded the warmest nights in Kerala.

4.5.1 Coastal zones

The minimum temperature over the coastal regions of Kerala from 1956 to 2009 showed an increase of 0.28°C (Fig.4.9). It was at the rate of 0.0052°C per year which is statistically significant at 5% level. The minimum temperature increased from 23.3°C in 1956 to 24.0°C in 2009. The highest minimum temperature (24.4°C) was recorded in 1983, 1987, 1997 and 1998 while the minimum temperature was the lowest (23.3°C) in 1956.

The decadal trend in minimum temperature indicated that the increase was dominant (24.1°C) during 1981-90 and 1991-2000 (Fig. 4.10). The decade 2001-2009 registered a decline of 0.3°C in minimum temperature over the previous decades, indicating that the warming of coastal belt of Kerala is not significant in terms of minimum temperature.

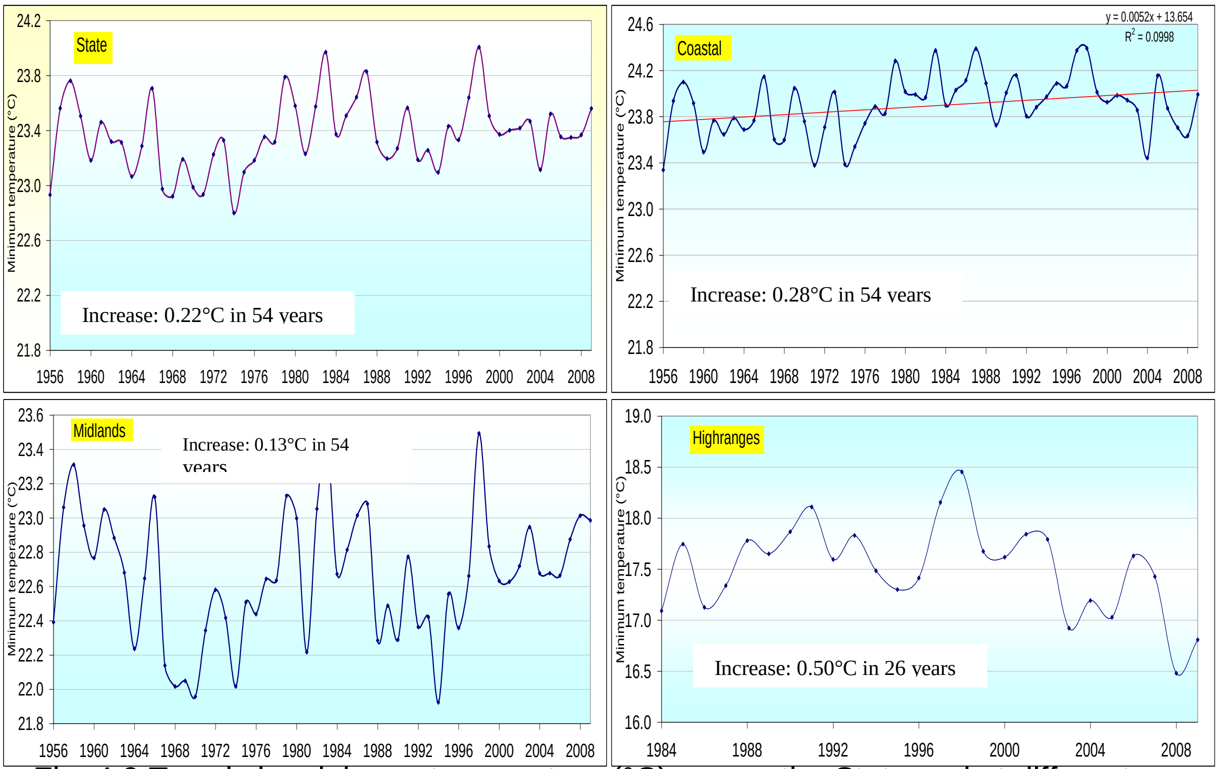


Fig. 4.9 Trends in minimum temperature (°C) across the State and at different zones

Fig. 4.10 Decadal trends in minimum temperature across the State and at different zones

4.5.2 Midlands

The minimum temperature over the midlands of Kerala from 1956 to 2009 showed an increasing trend of 0.13°C (Fig.4.9). The increase was at the rate of 0.0024°C per year which is not statistically significant. The highest minimum temperature (23.8°C) was observed in 1998 and the lowest (21.9°C) in 1994.

Decadal minimum temperature across the midlands of Kerala showed marginal decline at the rate of 0.0029°C per decade. The highest increase was observed in 1956-60 (22.9°C). The lowest was in 1961-70 (Fig. 4.10).

4.5.3 Highranges

Minimum temperature across the highranges of the State has declined by 0.5°C from 1984 to 2009, which is the highest decline in minimum temperature when compared to other zones (Fig.4.9) which was statistically insignificant. The minimum temperature was the highest in 1998 (18.5°C) while the lowest in 2008 (16.5°C).

Decadal analysis revealed that the minimum temperature is declining rapidly across the highranges of Kerala (Fig. 4.10). It was more so in the recent decade, during which the minimum temperature was the lowest (17.2°C). It was high (17.8°C) in 1991-00. It reveals that minimum temperature across the highranges is declining rapidly.

4.6 MEAN TEMPERATURE TRENDS ACROSS THE STATE

The mean temperature over Kerala from 1956 to 2009 showed an increase 0.47°C (Fig.4.11). The rate of increase was 0.0087°C per year. Increase in mean temperature was statistically significant at 1% level. The mean temperature increased from 27.0°C in 1956 to 27.9°C in 2009. The mean temperature was the highest (28.3°C) in 1987 and the lowest followed in 1956 (27.0°C). The mean temperature also was increasing marginally by 0.08°C/decade. The decadal trend in mean temperature also

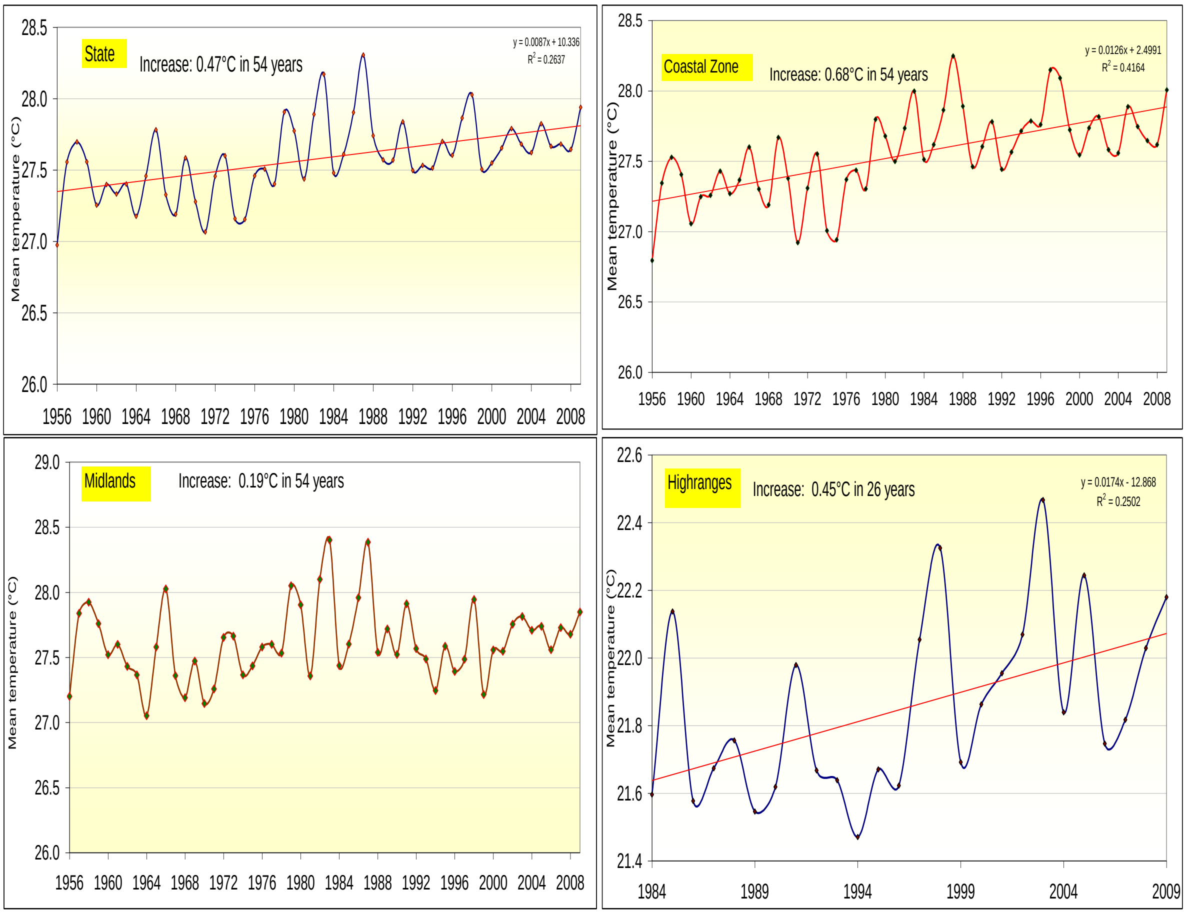


Fig.4.11 Trends in mean temperature across the State and at different zones

Fig. 4.12 Decadal trends in mean temperature across the State and at different zones

indicated that the increase was more from 1981-90 onwards. The highest decadal mean temperature (27.8°C) was observed during 1981-90 while the lowest (27.4°C) was noticed in the decades viz., 1956-60, 1961-70 and 1971-80 ((Fig. 4.12).

4.6.1 Coastal zone

The mean temperature over the coastal regions of Kerala from 1956 to 2009 showed an increase of 0.68°C (Fig.4.11). The rate of increase of 0.0126°C per in 2009 is statistically significant at 1% level. The highest mean temperature (28.2°C) was recorded in 1987 while the lowest (26.8°C) was in 1956. The decadal indicated that the increase was dominant in recent decades with the highest increase being observed in 1991-2000.

4.6.2 Midlands

The mean temperature over the midlands of Kerala from 1956 to 2009 showed an increase of 0.19°C (Fig.4.11). This increase at the rate of 0.0035°C per year is not significant statistically. The mean temperature has increased from 27.2°C in 1956 to 27.8°C in 2009. The highest mean temperature was observed in 1983 and 1987 (28.4°C). The lowest mean temperature (27.1°C) was noted in 1964 and 1970. The decadal analysis revealed that mean temperature was the highest in 1981-90 (27.8°C).

4.6.3 Highranges

The mean temperature across the highranges of Kerala has increased by 0.45°C since 1984. The rate of increase of 0.0174°C per year (Fig. 4.11) is statistically significant at 5% level. The highest mean temperature across the highranges was recorded in 2003 (22.5°C) while the lowest was 1989 and 1994 (21.5°C each). Decadal analysis showed that mean temperature has been increasing gradually over the decades (Fig. 4.12) while the highest (22.0°C) in the recent decade (2001-09).

4.7 TRENDS IN TEMPERATURE RANGES ACROSS THE STATE

The temperature range over Kerala from 1956 to 2009 showed an increase of 0.51°C (Fig. 4.13). The rate of increase of 0.0094°C per year is statistically significant at 1% level. The temperature range increased from 8.1°C in 1956 to 8.8°C in 2009. The highest temperature range (9.0°C) was recorded in 1987 while the lowest temperature range (7.9°C) was recorded in 1958 and 1961. Temperature range also showed a steady increase by 0.1143°C/decade. The range was 8.0°C during 1956-60 and gradually

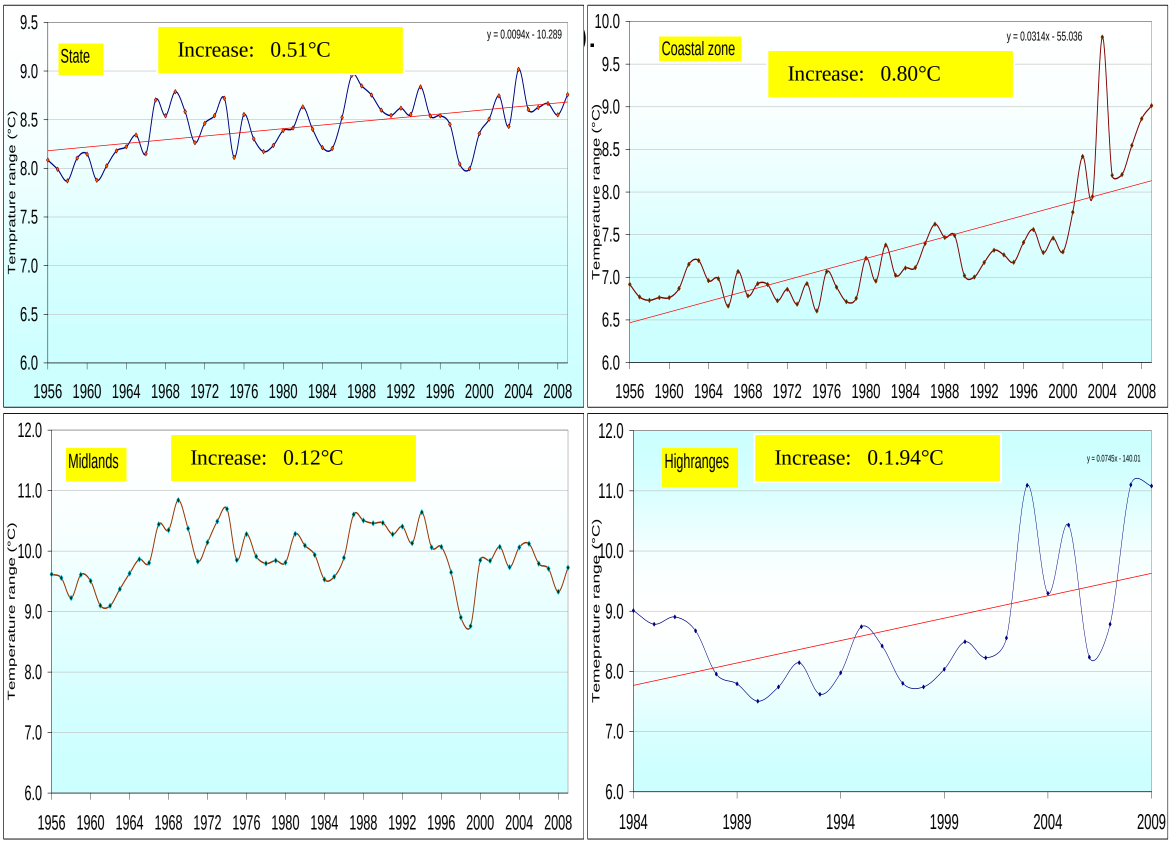


Fig. 4.13 Trends in temperature range across the State and at different zones

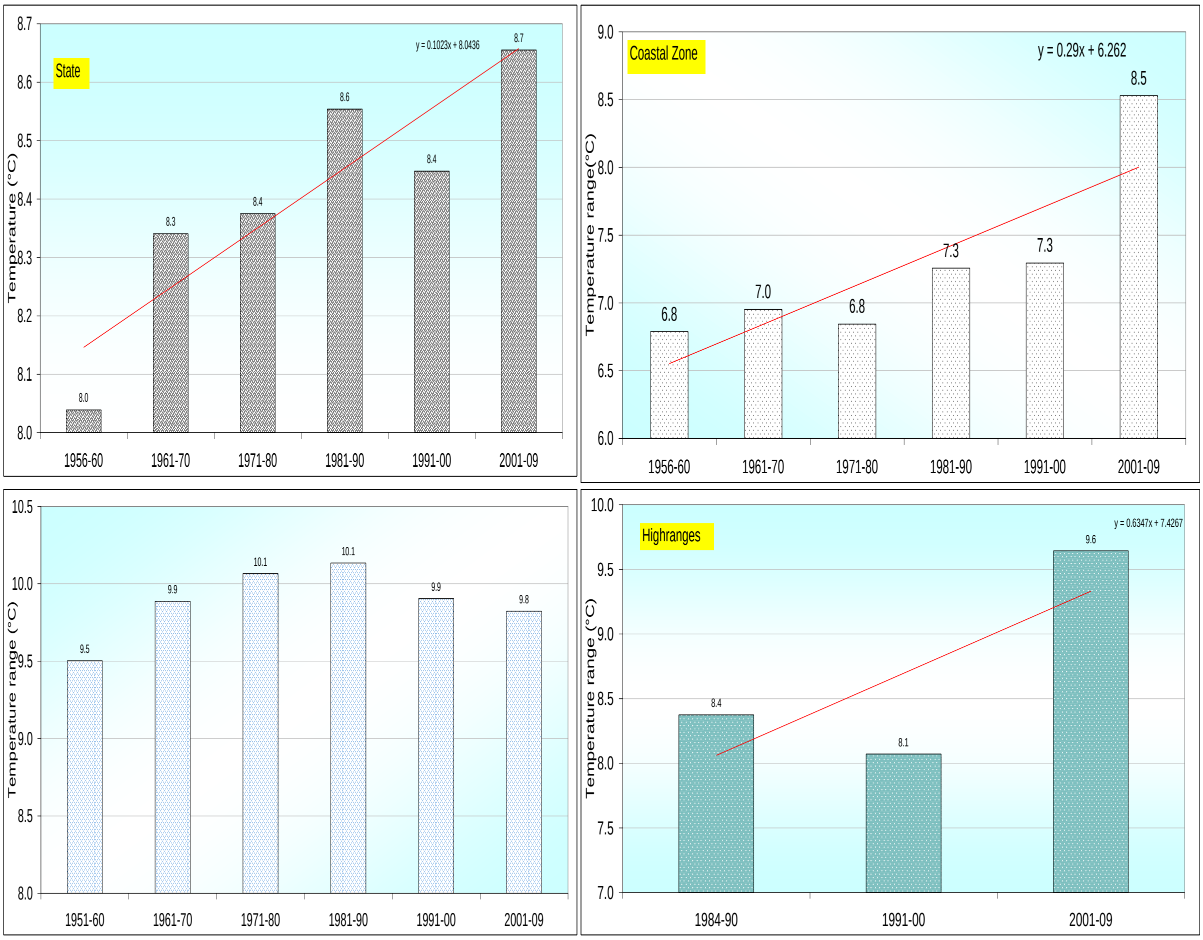


Fig.4.14 Decadal trends in temperature range across the State and at different zones

4.7.1 Coastal zone

The temperature range across the coastal regions of Kerala from 1956 to 2009 showed an increase of 0.80°C (Fig.4.13) at the rate of 0.0149°C / year which is statistically significant also at 1% level. The temperature range increased from 6.9°C in 1956 to 8.0°C in 2009. The highest mean temperature range (8.2°C) was recorded in 2004 while, followed the lowest (6.8°C) was in 1957.

The decadal trend in temperature indicated that the increase (7.8°C) was dominant in recent decade 2001-09 (Fig. 4.14). Increase in temperature range in the recent decades indicate the widening of temperature (difference between the day maximum and night minimum temperature) across the coastal belt of Kerala, which may have adverse impacts on thermo-sensitive crops

4.7.2 Midlands

The temperature range over the midlands of Kerala from 1956 to 2009 has increased by 0.12°C (Fig.4.13), at the rate of 0.0022°C per year which is not significant. The highest temperature range was observed in 1969 (10.8°C). The decadal temperature range showed an increasing tendency (Fig. 4.14), while the highest increase in temperature range being observed in 1971-80 and 1981-90 (10.1°C each).

4.7.3 Highranges

Annual temperature range across the high ranges has increased by 1.94°C (Fig.4.13), at the rate of 0.0745°C per year which is significant at 10% level. The highest temperature range was observed in 2003, 2008 and 2009 (11.1°C each), while the lowest in 1990 (7.5°C).

Decadal temperature trend also reveals that increase in temperature range is more conspicuous in the recent decade 2001-09 (Fig.4.14). It is pointed out that such situations will have serious deleterious effect on the performance of thermosensitive crops viz., tea, coffee, cardamom, cocoa and black pepper grown across the highranges of Kerala.

Warming Kerala, like global warming, is real as the maximum, minimum, mean and temperature range showed an increasing trend during the study period from 1956-2009. The study confirms that there was an increase in temperature, indicating that global warming in the State of Kerala is real in tune with global and regional scales. Interestingly, the rate of increase in maximum temperature was high (1.46°C) across the highranges, followed by the coastal belt (1.09°C) of Kerala while the rate of increase was relatively marginal (0.25°C) across the midlands. The rate of increase in temperature across the highranges is obvious because of deforestation while the increase in sea surface temperature may be the important factor along the coastal belt for the increase in rate of atmospheric temperature. The marginal increase in temperature across the midlands may be due to the predominant occupation of plantations like rubber, coconut and cashew. It indicates that the highranges and coastal belts in Kerala are more vulnerable in terms of the rate of increase in temperature.

At the current rate of increase in maximum temperature of 0.4°C during the recent decades, the increase in maximum temperature across Kerala is likely to be between 1.2°C and 1.6°C by 2051-80 and 2081-2100, respectively. It would be between 0.3°C and 0.4°C in the case of minimum temperature. Accordingly, the increase in mean temperature is likely between 0.59°C and 0.76°C during the period of 2051-80 and 2081-2100. In the case of temperature range, it would be between 0.89°C and 1.14°C by 2051-80 and 2081-2100, respectively (Fig.4.15).

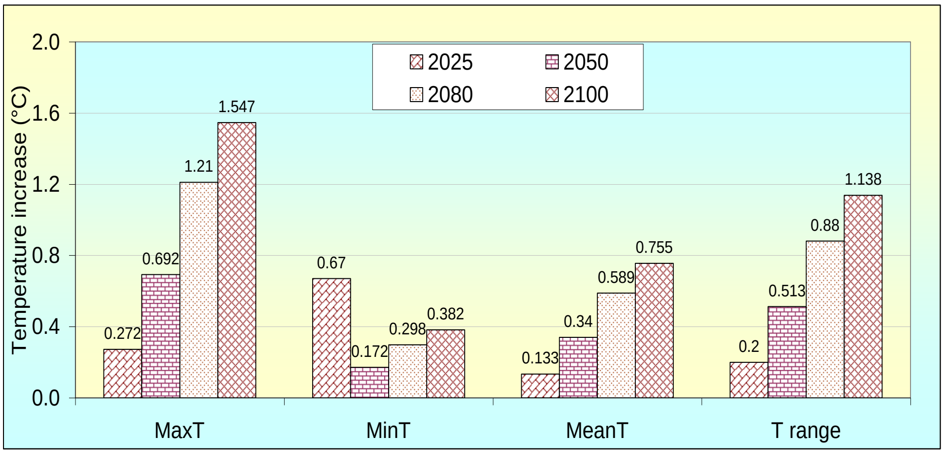


Fig.4.15 Projections in temperatures and temperature range (°C) across Kerala by 2025, 2050, 2080 and 2100A.D

4.8 ONSET OF MONSOON

Based on the long series of data from 1870 to 2010, the normal date of onset of monsoon was worked out and it is on 1st June with a standard deviation of seven days, varying between 25th May and 8th June (Fig. 4.16).

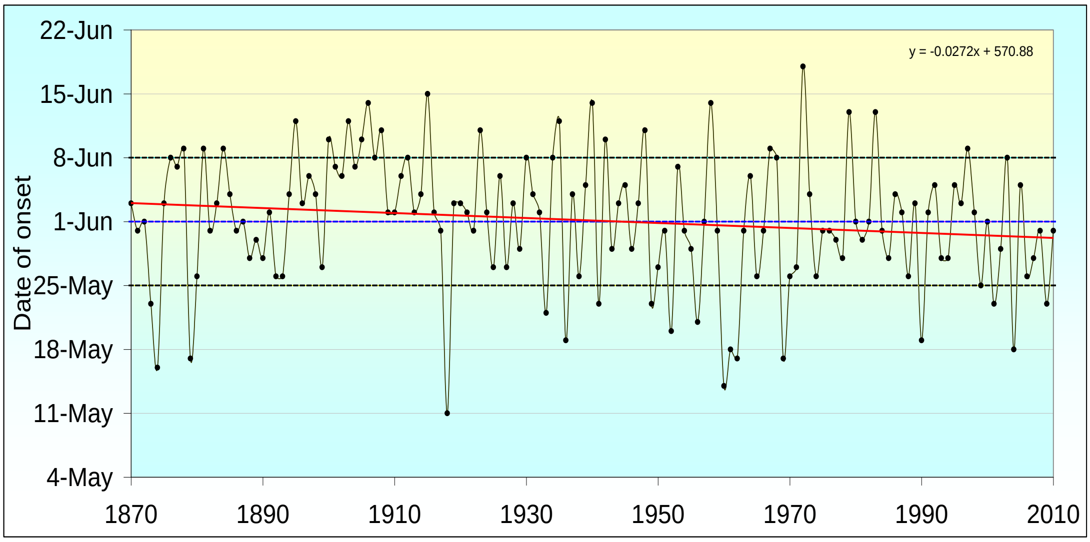


Fig. 4.16 Onset of monsoon over Kerala from 1870 to 2010

The monsoon directory of Kerala indicated that the earliest onset of monsoon was on 11th May in 1918 while belated monsoon on 18th June in 1972. Interestingly there was delay (4th June +/- 7 days) in normal onset of monsoon during 1901 -1930 though the standard deviation was the same to that of normal. Out of thirty years, six years only recorded the onset of monsoon before 1st June. Nevertheless, the earliest onset (11th May) of monsoon was also noticed during the above period in 1918 (Table 4.1).

Table 4.1 Tri-decadal variation in onset of monsoon over Kerala

Year	Mean onset	The earliest onset	The most belated onset	Std. Deviation (days)
1870-1900	1st June	16th May (1874)	12th June (1895)	7
1901-1930	4th June	11th May (1918)	15th June (1915)	7
1931-1960	31st May	14th May (1960)	14th June (1940)	8
1961-1990	31st May	17th May (1962)	18th June (1972)	8
1991-2011	30th May	18th May (2004)	9th June (1997)	6
1870-2011 (Normal)	1st June	11th May (1918)	18th June (1972)	7

( ) Figures in parenthesis indicate the year in which the onset of monsoon falls

4.9 ANNUAL RAINFALL

The mean annual rainfall over the state is 2828.2 mm +/- 405.4mm over a period of 138 years (1871 – 2008). Long series of climatological data for 138 years (1871-2008) over Kerala indicate cyclic trend in pattern with a declining trend in annual rainfall (Fig. 4.17), which was not statistically significant.

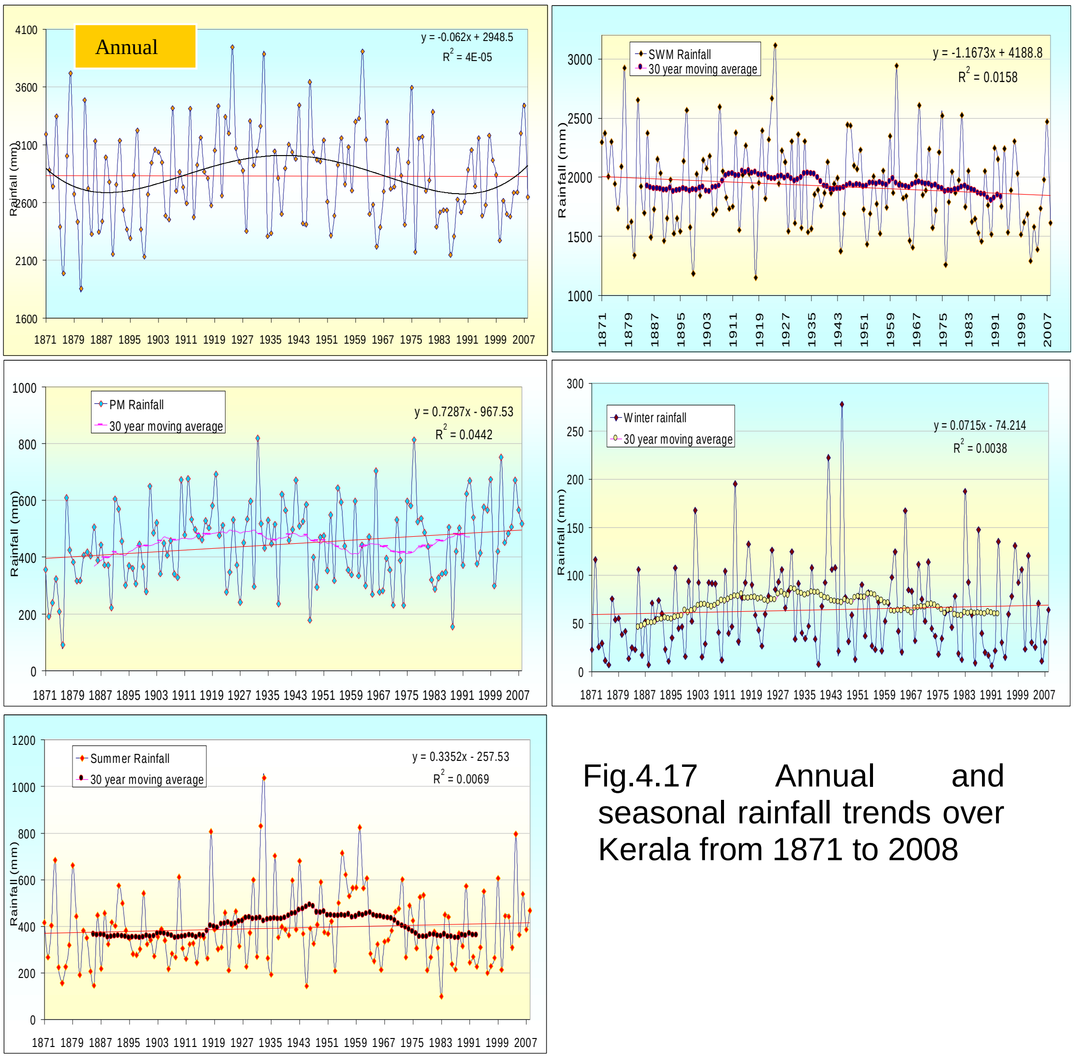


Fig.4.17 Annual and seasonal rainfall trends over Kerala from 1871 to 2008

4.10 SOUTHWEST MONSOON

The normal rainfall during the southwest monsoon over Kerala from 1871 to 2008 is 1924.9 mm with a coefficient of variation (CV) of 19.3%. The monthly rainfall was relatively undependable with August and September having a coefficient of variation of 41.5 and 54.1 per cent respectively (Table 4.2). The dependable rainfall during monsoon at 75 percent probability level was 1647.1 mm.

Table 4.2 Southwest monsoon rainfall (mm) in Kerala from 1871 to 2008

	Rainfall (mm)				
	June	July	August	September	Total
Normal rainfall(mm)	683.6	636.9	376.6	228.4	1924.9
Std Deviation	192.4	205.7	155.9	123.7	371.0
CV (%)	28.2	32.3	41.5	54.1	19.3
% contribution	35.5	33.0	19.5	11.9	100.0
Dependable rainfall (75% probability)	577.7	509.4	271.9	136.3	1647.1

Though the inter-annual variation of monsoon rainfall is significant, it was highly stable as the rainfall variability is within plus or minus one standard deviation from the normal rainfall. It also revealed that the monsoon rainfall over Kerala is declining by 161mm during the study period of 138 years (Fig. 4.17), which however was not statistically significant.

4.11 POST MONSOON

The normal rainfall during the post monsoon season over Kerala from 1871 to 2008 is 445.8 mm, which is about 15.7 per cent of annual rainfall. The post monsoon rainfall is relatively undependable with coefficient of variation being 31.1%. The dependable rainfall during post monsoon at 75% level was 341 mm (Table 4.3). .

Table 4.3 Post monsoon rainfall (mm) in Kerala from 1871 to 2008

	Rainfall (mm)		
	October	November	Total
Normal rainfall(mm)	289.6	156.2	445.8
75% probability	207.8	94.2	341.0
Standard deviation	107.4	85.1	192.9
Coefficient of variation (%)	37.1	54.5	31.1
Percentage contribution	65.0	35.0	100.0

Though the variation in inter-annual rainfall during post monsoon is significant, it was always within +/- one standard deviation from the normal rainfall. The rainfall during post monsoon season has an increasing tendency especially since 1961. An increase of 100.6 mm was noticed during the study period of 138 years (Fig. 4.17), which was statistically significant at 5% level.

4.12 WINTER

The normal rainfall during the winter season over Kerala from 1871 to 2008 is 64.4 mm which is a meagre 2.3 per cent of annual rainfall. The winter rainfall is highly undependable as the CV is 72.1 per cent. The dependable rainfall during winter season at 75% level was 104.4 mm (Table 4.4). An increase of 9.9 mm was noticed during the study period of 138 years (Fig. 4.17), which was not statistically significant.

Table 4.4 Winter rainfall (mm) in Kerala from 1871 to 2008

	Rainfall (mm)			
	December	January	February	Total
Normal rainfall(mm)	9.5	11.0	16.9	64.4
75% probability	9.9	0.4	2.8	104.4
Standard deviation	37.9	16.7	20.5	46.4
Coefficient of variation (%)	399.2	151	121.1	72.1
Percentage contribution	14.8	17.1	26.2	-

4.13 SUMMER

The normal rainfall during the summer season over Kerala from 1871 to 2008 is 392.6 mm (Table 4.5) which is 13.9 per cent of annual rainfall.

Table 4.5 Summer rainfall (mm) in Kerala from 1871 to 2008

	Rainfall (mm)			
	March	April	May	Total
Normal rainfall(mm)	36.6	111.7	244.3	392.6
75% probability	15.5	75.3	132.4	269.4
Standard deviation	32.7	51.3	157.7	160.8
Coefficient of variation (%)	89.4	45.9	64.5	41.0
Percentage contribution	9.3	28.5	62.2	100.0

The summer rainfall is fairly dependable as the CV is relatively low (41.0 %). The dependable rainfall during summer season at 75% level was 269.4 mm. The seasonal trend graph showed that summer rainfall has increased by 45.4

mm over a period of time (Fig. 4.17), which is not significant statistically. Rainfall in March has a high CV of 89.4%, followed by May (64.5%) and April (45.9%). Major share of seasonal rainfall comes from May (62.2%) followed by April (28.5%) and March (9.3%).

4.14 DECADAL AND TRI-DECADAL TRENDS IN RAINFALL ACROSS KERALA

The decadal trend in annual rainfall over Kerala showed that it was marginally declining over a period of time that is not significant statistically. The decadal rainfall was high (3061.7 mm) in the decade 1921-30, followed by 1941-50 (3002.5 mm). The decadal rainfall was low (2555.7 mm) in 1981-90, which was the warmest decade in Kerala (Fig. 4.18). It revealed that there was an increase in decadal rainfall till 1950s and thereafter there was a significant decrease in rainfall in recent decades. It was more so in the decade 1981-90.

In the case of monsoon rainfall too, it was declining marginally by 2.98 mm/decade. It was high (541.9 mm) in the decade 1921-30, followed by 1871-80 (521.8 mm) and 1941-50 (503.8 mm). The ever highest flood of 1924 was in the decade 1921-30 (Fig. 4.18). It may be interesting to note that that the lowest average decadal rainfall was observed the decade 2001-08. The vagaries of southwest monsoon in recent years could be attributed to the declining rainfall. It may also be noted that only one year (2007) fell under the category of excess rainfall during the decade 2001-08. It also revealed that decadal rainfall during June and July is declining at the rate of 28.6mm/decade and 13.6mm / decade, respectively. At the same time, decadal rainfall during August and September is in increasing trend - 2.3 mm/decade during August and 7.5 mm/decade in September.

Decadal post monsoon rainfall over Kerala showed that the rainfall is increasing over a period of time unlike annual and SWM rainfalls (Fig. 4.18).

The increase is at the rate of 7.6 mm/decade and it is statistically significant at 10% level. The highest rainfall was received during the decade 2001-08 (545.7 mm) followed by 1911-20 (542.5 mm). The lowest was recorded during 1871-80 (313.7 mm). It also revealed that the decadal rainfall during October has been increasing at the rate of 4.89 mm/decade while the increase was 2.78 mm/decade in November.

Decadal rainfall during winter showed a marginal increase at the rate of 0.63 mm per decade over the decades. The highest rainfall was (100.9 mm) was recorded during 1941-50 followed by 86.8 mm during 1911-20. The lowest (41.1 mm) was recorded during the decade 1881-1990.

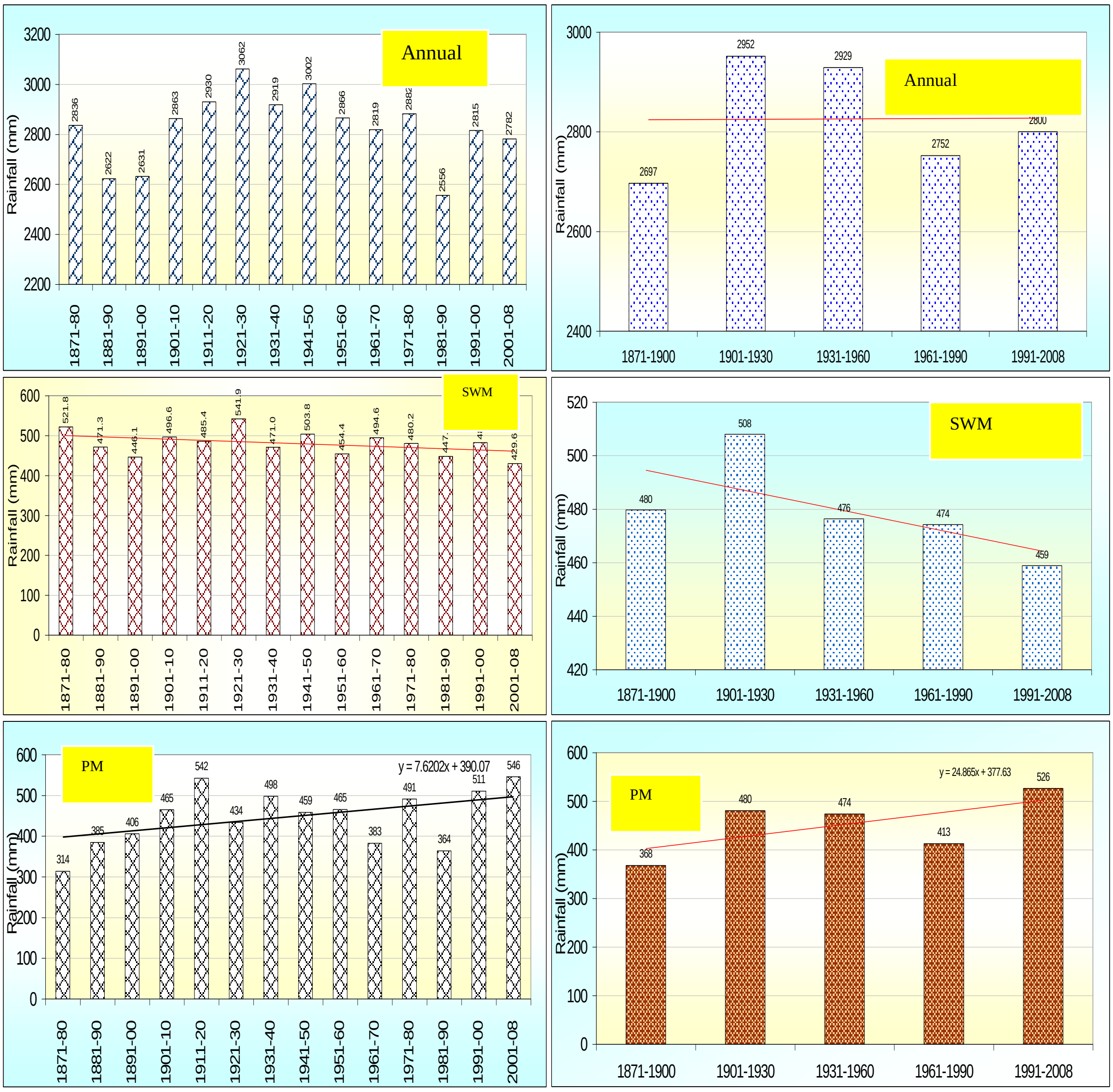


Fig.4.18 Decadal and tri-decadal trends in annual rainfall, southwest monsoon rainfall and post monsoon rainfall

Decadal rainfall during winter showed a marginal increase at the rate of 0.63 mm per decade over the decades. It is not significant. The highest rainfall was (100.9 mm) was recorded during 1941-50 followed by 86.8 mm during 1911-20. The lowest (41.1 mm) was recorded during the decade 1881-1990. Tri-decadal rainfall also showed an increasing trend (@ 1.53 mm/30 year).

In the case of summer rainfall also, the decadal trends indicated an increasing trend at the rate of 3.5 mm/ decade, which is not significant while the tri-decadal increase was 5.3 mm/30 year. The highest rainfall was received during the decade 1951-60 (532 mm) followed by 1931-40 (479.8 mm) while the lowest was 1991-2000 (311.6 mm). The highest rainfall received during the tri-decade 1931-60 (479.3 mm) and the lowest in 1901-30 (360.1mm)

A decline in monsoon rainfall and an increase in post monsoon rainfall were the trends obtained for the State of Kerala as a whole, though cyclic trends of 40-60 years were noticed in the annual rainfall. Of course, the decline in annual rainfall is evident since last 50-60 years over the State of Kerala. The study revealed that the contribution of southwest monsoon rainfall to the annual is declining while the post monsoon contribution is increasing. The contribution of southwest monsoon rainfall has declined by 5.6% while that of post monsoon has increased by 3.7% over a period of 139 years since 1871. It was also evident that rainfall during June and July is declining and that of August and September is increasing. Though the onset of monsoon is stable, varying between 25th May and 8th June, the uncertainties in monsoon rainfall are felt much more in recent years. It can be attributed to global warming and climate change.

4.15 CLIMATE SHIFTS OVER KERALA

Climatologically, Kerala falls under the climate type of "B4 humid" based on moisture index (Im=81.9%) of 109 years. The moisture index climbed higher into "B4 humid" and "A perhumid" types in 34 and 35 years, respectively. The climate was in "B3 humid" climatic type during 39 years and went into the drier climates such as "B2 humid", "B1 humid" and "C2 moist sub humid" in the remaining 31 years. More significantly, the moisture index has declined by 33.9% from 1901-2009, indicating that the climate shifted from wetter moisture regimes to comparatively drier moisture regimes within the humid climate type (Fig.4.19), which is significant at 1% level.

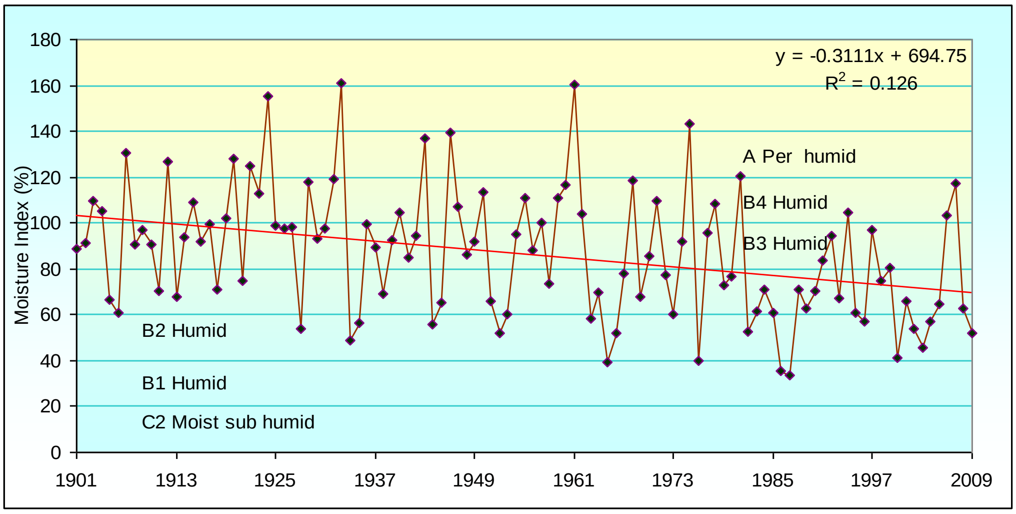


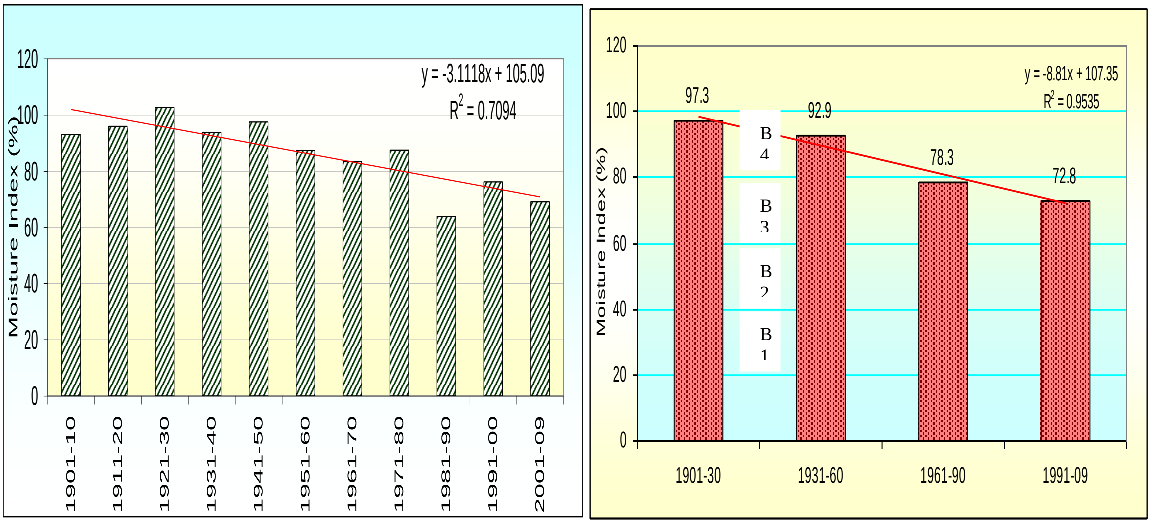
Fig. 4.19 March of moisture index from 1901 to 2009 over Kerala.

Only four years fell under the perhumid (A) category since last 29 years (Table 4.6), indicating that the State of Kerala was moving from wetness to dryness within the humid climate. It was more so since last three decades.

Table 4.6 Climate shifts over Kerala from 1871 to 2009

Decade	Climatic type						
	C2	B1	B2	B3	B4	A	Total
1901-1910	0	0	0	2	5	3	10
1911-1920	0	0	0	3	3	4	10
1921-1930	0	0	1	1	4	4	10
1931-1940	0	0	2	1	4	3	10
1941-1950	0	0	1	1	4	4	10
1951-1960	0	0	1	3	2	4	10
1961-1970	0	0	3	3	1	3	10
1971-1980	0	0	1	4	2	3	10
1981-1990	0	2	1	6	0	1	10
1991-2000	0	0	2	3	4	1	10
2001-2009	0	0	4	3	0	2	9
Total	1	6	24	39	34	35	139
Climatic shifts (%)	0.0	1.8	14.7	27.5	27.4	29.4	

The decline in moisture index is experienced more in the recent five decades (Fig.4.20). The climate shift towards drier side was more in the decade 1981-90 as two years fell under the 'B1' Climate, one year in 'B2' and 6 years in 'B3' climate. There were no years under B4 climate. At the same time, one year fell under per humid climate. Such a trend was seen before 1900.



4.20 Trends in decadal and Tri-decadal moisture index over Kerala from 1901 to 2009

During 1881-1890, one year even fell under 'C2' moist sub humid type. However, 1981-90 and 1991-2000 was typical in recent decades as only one year was seen on wet side (per humid). If it is studied on a seasonal basis, the scenario of climate shifts will be different. The moisture index is declining at the rate of 8.81 per cent per 30 year. It has declined by 25 per cent from 1901-30 to 1991-09.

The shifts in climate are as a result of changes in thermal and moisture regimes. Such climatic shifts may lead to changes in biomes and extinct of some flora and fauna across the Western Ghats which is one of the hot spots of rich biodiversity in the tropical rain forests. It has been reported that one-third of the State's biodiversity would vanish or would be close to extinction by 2030. Of the 300 rare, endangered or threatened species in the Western Ghats, 159 are in Kerala. Of these 70 are herbs, 23 climbers, eight epiphytes, 15 shrubs and 43 trees. Besides, 10 species of fresh water fish are identified as most threatened. Kerala has a flora of 10035 species, which represents 22% of Indian flora. Of these, 3872 are flowering plants of which 1272 are endemic. As many as 102 species of mammals, 476 birds, 169 reptiles, 89 amphibians and 262 species of fresh water fish are reported from Kerala. Many of these are endemic. During the 20th Century at least 50 plant species became extinct in the Country. It may be noted that nearly 23% of the total endemic flora species of the country are in Kerala. Of 1272 such species, 102 species occur exclusively in Kerala (Economic Review, 2003).

4.16 OCCURRENCE OF CLIMATOLOGICAL DROUGHTS OVER KERALA

The State of Kerala experienced 53 drought years out of 109 (1901-2009), of which 17 were moderate, 19 large, 13 severe and four disastrous droughts (Table 4.7). The decades 1991-2000 witnessed the maximum number of droughts (seven), followed by 1961-70, 1971-80, 1981-90 and 2001-09 (six each). The number of disastrous droughts was also more (two) during 1991-2000, followed by 1951-60 and 1981-90 (one each) indicating that the intensity of drought is increasing in the recent decades. There was decline in the number of droughts during the decade 1941-50 and 1951-60 (two each). It was evident that the number of droughts was on higher side since last fifty years and the intensity was more during summer if pre-monsoon showers fail. During the same period, aridity index over Kerala has increased by 3.32 %, indicating that Kerala is moving towards dryness.

Table 4.7 Occurrence and intensity of droughts in Kerala from 1901 to 2009

Decade	Intensity of drought					Occurrence of drought (%)
	Moderate	Large	Severe	Disastrous	Total	
1901-10	2	2	1	0	5	50
1911-20	2	2	0	0	4	40
1921-30	2	2	1	0	5	50
1931-40	2	0	2	0	4	40
1941-50	0	1	1	0	2	20
1951-60	1	0	0	1	2	20
1961-70	3	2	1	0	6	60
1971-80	3	2	1	0	6	60
1981-90	0	1	4	1	6	60
1991-00	0	3	2	2	7	70
2001-09	2	4	0	0	6	60
Total	17	19	13	4		
Drought Intensity (%	32.1	35.9	24.5	7.5	53	

The intensity of drought was maximum (35.9%) under the category 'large' followed by moderate (32.1%) and severe (24.5%) while it was less (7.5%) under the category of disastrous (Fig. 4.21). There were no disastrous drought years in the history of State from 1901 to 1950.

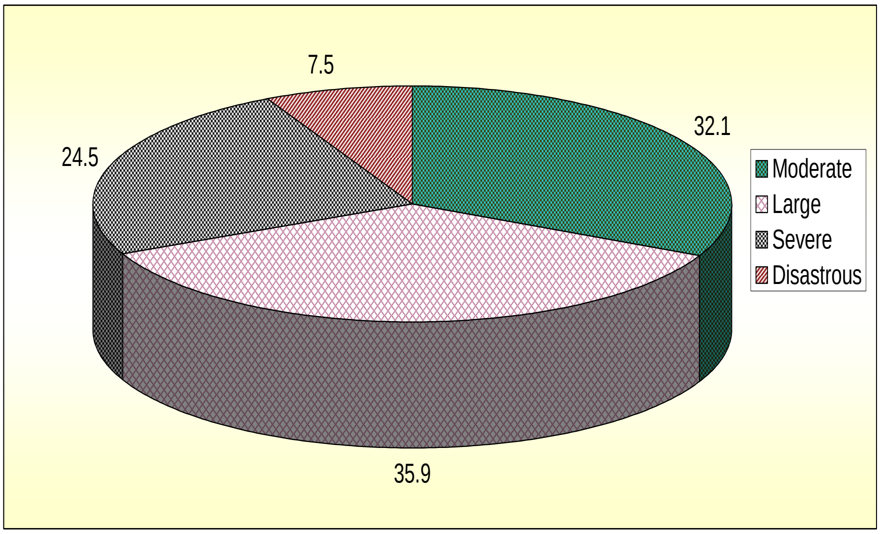


Fig. 4.21 Intensity of climatological droughts (%) over Kerala

The disastrous drought was noticed in the year 1953 during the decade 1951-60 for the first time, followed by 1983, 1991 and 1996 in recent decades. It revealed that the occurrences and intensity of droughts were increasing in the recent decades. The march of aridity index over the State also showed a marginal increasing trend since last 110 years (Figs. 4.22 and 4.23), which is significant at 5% level.

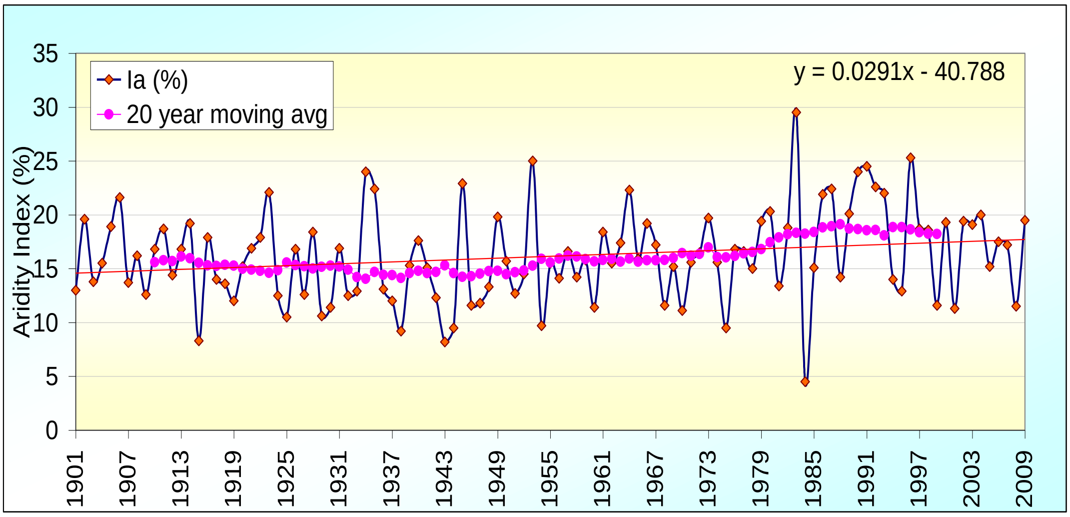


Fig.4.22 March of aridity index (%) over Kerala from 1901 to 2009

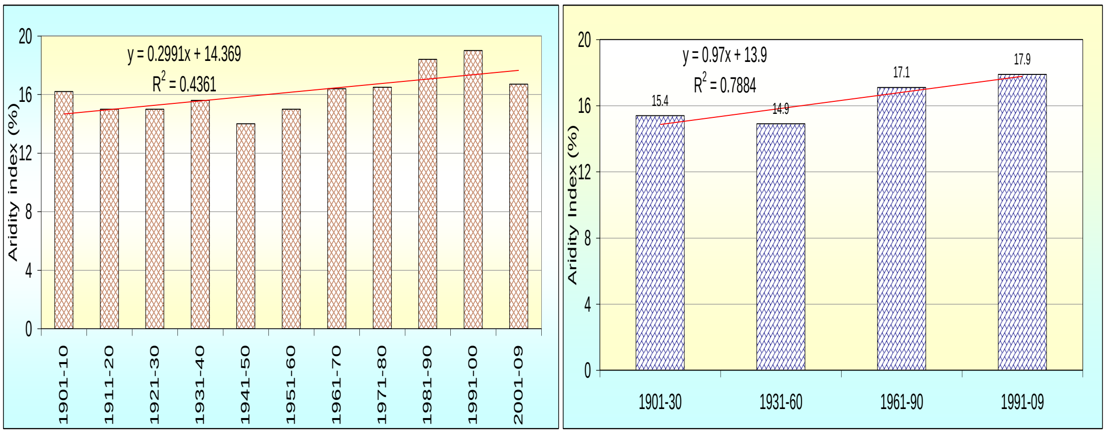


Fig. 4.23 Decadal and Tri-Decadal aridity index (%) over Kerala from 1901 to 2009

Tri-decadal variability of aridity index also confirms the fact that it was increasing over a period of time, though it showed a marginal decline during the tri-decade 1931-60. The present study reveals that the climate change is real in Kerala. Increase in temperature, decline in rainfall, dryness within the humid climate, increase in aridity index and number of climatological droughts are the major findings observed in the State of Kerala. The above changes in climatic parameters are the indicators of evidence of climate change in Kerala since last 140 years.

Chapter 5

Climate variability and food security

5.1 IMPACT OF DROUGHT ON INDIAN FOODGRAINS PRODUCTION

The Indian economy is mostly agrarian based and depends on onset of monsoon and its further behavior. The year 2002 was a classical example to show how Indian foodgrains production depends on rainfall of July. The year 2002 was declared as all India drought, as the rainfall deficiency was 19% against the long period average of the Country and 29% of area was affected due to drought. The *kharif* foodgrains production was adversely affected by a whopping fall of 19% due to all-India drought during monsoon 2002. The All India drought is defined as the drought year when the rainfall deficiency for the Country as a whole is more than 10 per cent of normal and more than 20 per cent of the Country's area is affected by drought conditions. The all India drought could be attributed to the monsoon breaks / failure during the *khairf* season. As the area under cultivation during the first crop season is mostly rainfed across the Country, the distribution of monsoon rainfall during July play a predominant role for crop spread. The Indian foodgrains production increased from 50 million tonnes in 1950-51 to 230 million tonnes in 2007-08 and 2008-09 (Fig.5.1). Both the recent years were record years in terms of foodgrains production in India. Though the increase in foodgrains production was more than four folds, the inter-annual/intra-seasonal variations were not uncommon due to the occurrence of floods and droughts. The inter-annual dips in the production of foodgrains are mostly due to the failure of monsoon and consequent droughts. Droughts in 1965-66 and 1966-67, 1979-80, 1987-88, 2002-03 and recent drought in 2009-10 affected the Country's foodgrains production to a large extent. The effect of drought on Indian foodgrains production is felt much more when compared to that of floods as large areas under cultivation is adversely affected due to drought.

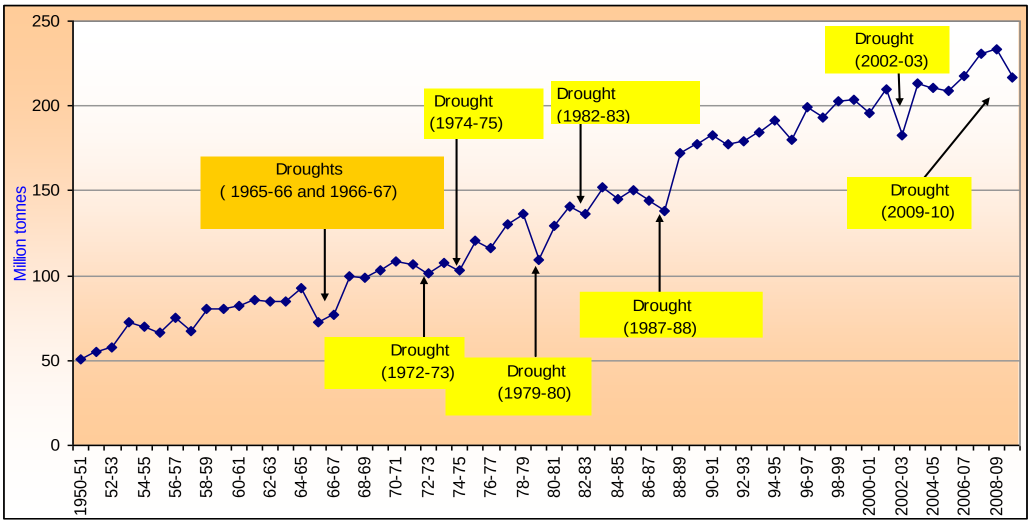


Fig.5.1 Impact of droughts on Indian foodgrains production from 1950- 51 to 2009-10

As per the Economic Review (2009), the years 1965, 1966, 1972, 1974, 1979, 1982, 1987, 2002 and 2009 were classified as the drought years during which the deficit of monsoon rainfall against normal varied between 7.7 and 22 per cent (Table 5.1). Whenever the monsoon rainfall was deficit and depending upon its distribution, the Indian foodgrains production was

Table 5.1 Effect of drought during monsoon on Indian foodgrains production

Drought years	Monsoon rainfall (June-Sept) in mm	% deficit over the normal	Foodgrains production (million tonnes)	% decline in foodgrains production over previous year
1965	741.1	-17.1	72.35	28.5
1966	802.2	-10.3	77.0	20.8
1972	708.4	-20.8	107.0	5.9
1974	825.4	-7.7	103.5	3.9
1979	723.3	-19.1	109.0	24.8
1982	788.4	-11.8	136.5	2.9
1987	739.6	-17.3	138.4	4.1
2002	715.5	-20.0	183.0	14.8
2009	697.3	-22.0	216.0	7.6
Average decline in Indian foodgrains production (%)				12.5

adversely affected. The effect of drought during monsoon on Indian foodgrains production varied between 2.9 and 28.5 per cent, depending upon the drought intensity. The average decline in Indian foodgrain production due to drought during monsoon season, which coincide with *kharif* season was 12.5 per cent.

As indicated, the effect of drought on Indian foodgrains production depends on the distribution of rainfall during July and August. If the deficit rainfall during July and August is more and more with erratic distribution, the effect of drought on Indian foodgrains production is also more.

On pentads also, it is clearly brought out the effect of drought on Indian foodgrains production. The rate of increase in Indian foodgrains production was slowed down due to occurrence of droughts. The decline in Indian foodgrains was seen in 1966-70 (4.8%), 1986-90 (11.2%), 1996-00 (7.0%), 2001-05 (3.4%) and 2005-10 (9.3%) against the normal rate of increase of 12.5 per cent. Therefore, it is evident that the Indian foodgrains production was not in tune with the plan estimates since last 15 years (Fig. 5.2). It was mainly attributed to the ill effects of droughts and floods and cold and heat waves during the crop growing seasons as the *kharif* foodgrains production is dependent on monsoon rainfall while *rabi* foodgrains is dependant on cold and heat waves. Of course, the technological interventions in recent years may be one of the factors for reducing the effect of drought on Indian foodgrains production. At the same time, the effect of drought during monsoon on Indian foodgrains production would be much more if the production during *kharif season* alone was considered. Therefore, it is possible to predict the *kharif* foodgrains production based on summer monsoon rainfall as majority of the foodgrains crops are grown during the *kharif* under rainfed conditions and depend on monsoon rainfall and its distribution. Such an attempt was made by Parthasarathy *et al.,* (1998) and Ramakrishna *et al.,* (2003). They developed a statistical equation to predict the Indian foodgrains production based on Indian summer monsoon rainfall.

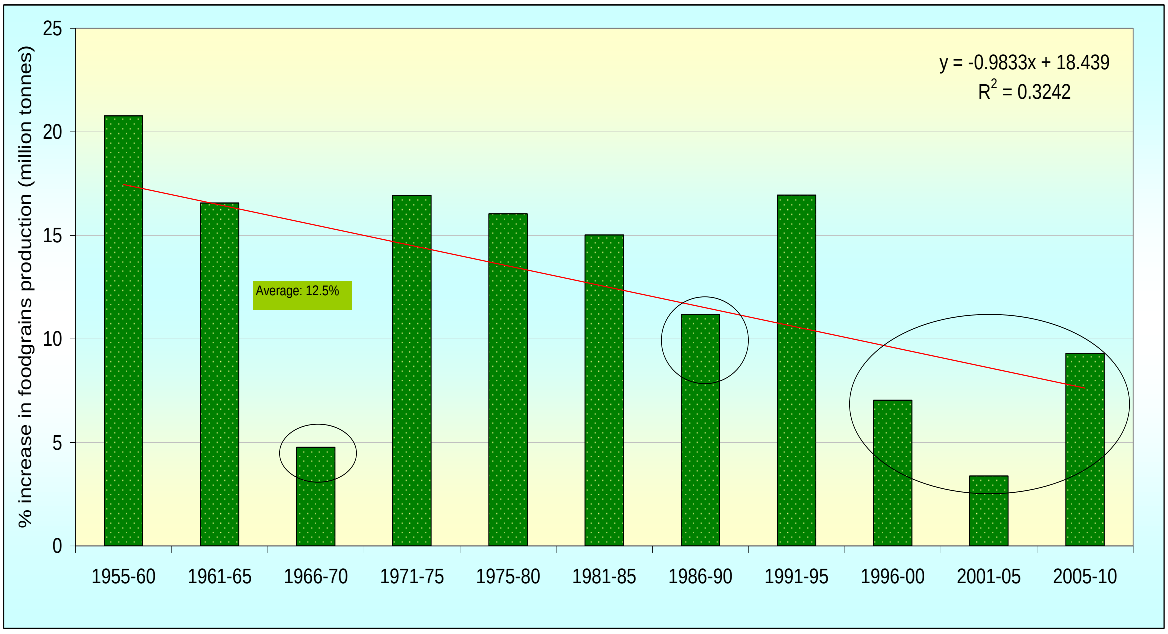


Fig.5.2 Rate of percentage increase in Indian foodgrains production

The frequency of weather aberrations is likely to increase under the projected climate change scenario across the Country in ensuing decades and the Indian foodgrains production is adversely affected while the demand for the same will be more due to increase in human population. As per the ICMR estimates, the requirement of foodgrains is 260 million tonnes by 2010 and about 310 million tonnes by 2020 according to the increase in human population (Table 5.2). Interestingly, the rate of increase in Indian foodgrains production was only about 3 million tonnes per year and at this rate, the

Table 5.2 ICMR Dietary requirements for a balanced diet

Crops	Requirement per day in gms	Requirement in million tonnes		
		2000	2010	2020
Cereals and millets	420	198.7	237.4	280.99
Pulses and legumes	40	18.92	22.61	26.76
Foodgrains	460	212.62	260.01	307.75
Roots and tubers	75	35.48	42.39	50.18
Vegetables	125	91.66	109.52	129.62
Fruits	50	36.66	43.81	51.85
Milk	150	70.96	84.79	100.35
Fats and oils	22	10.41	12.44	14.72
Sugar	30	14.19	16.96	20.07
Egg	45	21.29	25.44	30.11
Meat	25	11.83	14.13	16.73
Fish	25	11.83	14.13	16.73
Population (millions)	-	1004.5	1200.17	1420.54

Source: UN Long Term Populations, ICMR-Dietary requirements for a balanced diet

increase in foodgrains production by 2020 would be 260 million tonnes only (Fig. 5. 3). Even to achieve the above target is in doubt due to stagnation in Indian foodgrains production under weather uncertainties as a part of global warming and climate change.

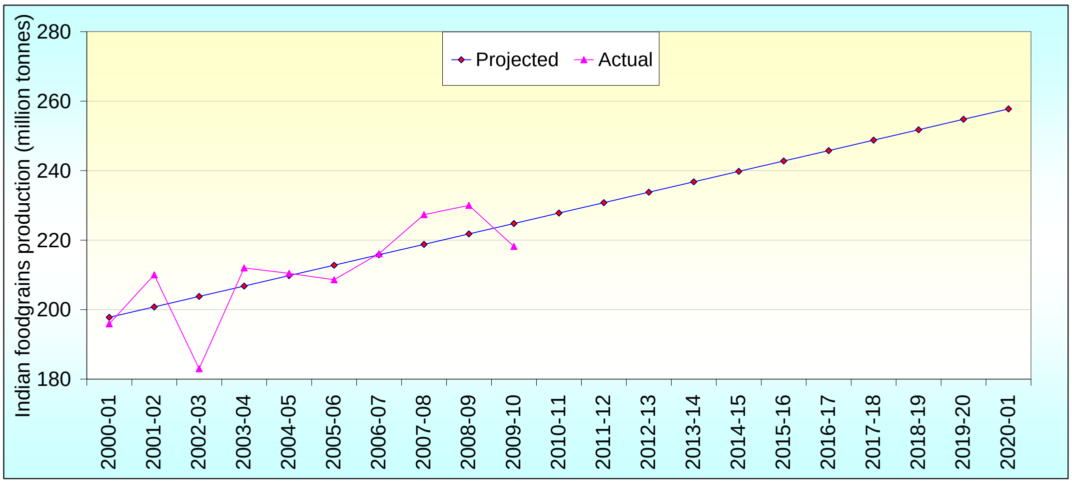


Fig. 5.3 Projected Indian foodgrains production from 2000-2021

No doubt, it may lead to deficit in Indian foodgrains production due to occurrence of floods and droughts and heat and cold waves. Studies indicate that by 425 ppm carbon dioxide concentration and an increase of 2°C, wheat area at different productivity levels in India is likely to decline. Similar was the case in the case of rice also (Sinha and Swaminathan, 1991). Therefore, pro-active measures are the need of the hour to increase the Indian foodgrains production against the ill effects of weather aberrations for which location/region/crop specific technologies are to be evolved as a part of climate change adaptation in agriculture.

5.2 CLIMATE CHANGE IMPACTS ON INDIAN FOODGRAINS PRODUCTION

Studies revealed that the maximum, minimum, mean and temperature range over the Country has increased by 0.76°C, 0.22°C, 0.49°C and 0.54°C, respectively during the period from 1901 to 2003. Based on this, temperature projections were worked out for 2020, 2050 and 2080 (Table 5.3) to understand the impact of increased temperature on rice production in India under the projected climate change and global warming scenario.

Table 5.3 Projections in temperature (°C) over the Country

Year	Max T	Min T	Mean T	Range
2020	0.9	0.7	0.7	0.3
2050	1.9	1.4	1.4	0.6
2080	2.8	2.1	2.1	0.9

Projections indicated that the maximum temperature across the country is likely to increase by 0.9°C by 2020, 1.9°C by 2050 and 2.8°C by 2080. Of course, the rate of increase is determined by the emission of GHGs, predominantly by carbon dioxide, as it contributes lion-share to global warming. The minimum and mean temperature projections follow the similar trend. The increase in minimum temperature is likely to be 0.7°C, 1.4°C and 2.1°C, respectively by 2020, 2050 and 2080. The temperature range across the Country is likely to increase by 0.6°C-0.9°C by 2050 and 2080. Moreover, the rate of increase in temperature is relatively high in post monsoon, followed by winter. It is a concern in northern States during *rabi* season as the winter crops are adversely affected due to temperature increase. It is pointed out that wheat crop will be badly affected in such an event. Warmer nights adversely affect the physiological processes of seasonal crops. It is reported that increase in minimum temperature will slow down the growth of rice production in Asia. Increase in day temperature can increase the yield up to a certain level, but future yield losses caused by higher night time temperature will likely outweigh any such gains as the temperatures are rising faster at night. If day time temperatures get too high, it too restrict the yield, causing additional yield reduction (Science Daily, 30th October, 2010). Warmer nights can be an indicator of climate change. This will have far reaching impact on the yield of rice and wheat, causing a shortfall in an important staple crop in a crowded country already struggling with food security and inflationary issues.

It is quite evident from the projected temperature that the annual mean temperature by 2050 is likely to be 1.4°C, and as a result the paddy and wheat yield are going to be adversely affected. As per the studies, yield reduction is likely to be around 10 per cent for every 1°C rise in temperature. Further increase in temperature during the ensuing years after 2050 will witness for a deficit foodgrains production, in the event of climate change and global warming under the projected increase in temperature. The crop production is likely to decline by 30 per cent over India by 2080 A.D. according to UNIDA.

On all India level, annual rainfall, southwest and post monsoon and winter rainfall has shown an increasing trend, while annul summer rainfall showed a marginal declining trend. Global climate models also projected increase in rainfall over the country, though some models project rainfall deficit across some regions of the country. During the first crop (*kharif) season* July rainfall is critical. As such, the projections in rainfall indicate that monsoon rainfall over India is in increasing trend. In a country, where the agricultural production is solely dependent on monsoon rainfall, its timely onset, distribution and quantum of rainfall are very important for reaping a better yield. Uncertainties in the onset of monsoon, weak monsoon flow, and long spells of break are serious issues as far as the Indian agriculture is concerned. In the event of monsoon breaks, the nation often faces drought like situation. Drought could be caused by weak/deficit monsoon rainfall as happened in 2002 and 2009 in the recent years. Since the monsoon is a global scale phenomenon, it is a complex one to be understood properly. As majority of the agricultural land is under rainfed, monsoon failure will definitely push the nation to low foodgrains production. Post monsoon rainfall is also in increasing trend across the Country. Post monsoon rainfall is important for *rabi* crop, mainly to wheat. Post monsoon rainfall, though lesser in quantity is essential for the second crop in the northern States of the Country as it is the source of soil moisture to the seasonal crops. Under the projected climate change scenario, it is the uncertainties in monsoon, occurrences of extreme weather events like droughts and floods, heat and cold waves, hail storms, cloud bursts, will adversely affect the crops to a large extent. It indicates that the foodgrains production is more vulnerable to climate variability and it is an immediate threat when compared to climate change. Therefore, it is high time to go for proper adaptation strategies to evolve suitable varieties in the case of wheat and rice and other foodgrains crops to withstand against the extreme weather events for sustenance of agricultural production in India.

5.3 CHANGES IN CROPPING PATTERN ACROSS KERALA

A clear shift was noticed from foodgrain crops to non-foodgrain crops in Kerala over a period of time due to various reasons**.** Increase in area under coconut, arecanut, banana, black pepper, and rubber was noticed at the cost of phenomenal decline in rice area (Table 5.4). The decline in paddy area was 70 per cent while increase in rubber was 285 per cent. The increase in area of coconut, arecanut, banana and black pepper was intermediary, varying between 39 and 76 per cent.

Table 5.4 Change in area and production of important crops in Kerala

Crop	Area(ha)		% variation
	1961-62	2007-08	
Paddy	753009	228938	-70
Coconut	505035	818812	62
Arecanut	56764	99787	76
Banana	42693	59341	39
Black pepper	99887	175679	76
Rubber	133133	512045	285

Source: Economic Review, GoK, 2009

Being a plantation State, non-foodgrain crops are predominantly grown when compared to that of foodgrain crops. Under the projected climate change scenario, there is a need to give weightage for foodgrain crops as they are declining globally, leading to food deficit and food insecurity. Keeping this in view, the Govt. of Kerala took initiatives to increase paddy production as a part of food security programme unlike in previous years. The paddy area drastically declined due to various socio-economic factors. The cost of cultivation, low productivity due to soil degradation, non-availability of farm labourers and non-remunerative price are the major factors, why, rice area is less at present. The area under the foodgrain crops varied between 42.28 and 43.5 in terms of index while it was between 86.82 and 121.24 in the case of non-foodgrain crops. Similar was the trend in the case of production (Fig. 5.4) of foodgrain and non-foodgrain crops.

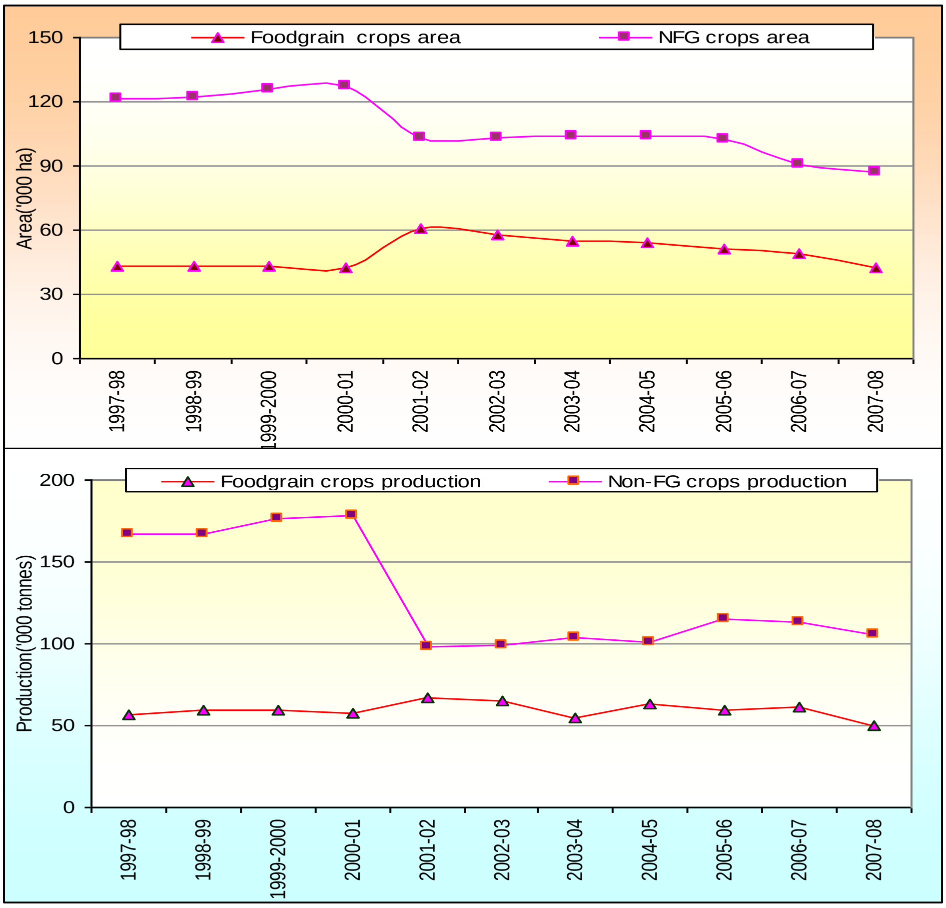


Fig.5.4 Shift in area and production index of foodgrain crops to non-foodgrain crops in Kerala

5.4 TREND IN AREA, PRODUCTION AND PRODUCTIVITY OF PADDY IN KERALA

Long series of data on area and production of paddy revealed that the area under the crop has come down drastically. The area during

1952-53 was 7.42 lakh ha which fell down to 5.6 lakh ha in 1990-91, again came down to 2.54 lakh ha in 2009-10. Over a period of 58 years (1952-53 to 2009-10), the paddy area in the State has declined by 65.8 per cent. A sudden decline in area was noticed since 1995-96. The lowest area under paddy cultivation was in 2007-08 (2.29 lakh ha) which was a flood year in Kerala. The area under rice has been declining consistently over the last several years. It is interesting to note that the area under paddy has increased marginally during 2008-09 and 2009-10 when compared to 2007-08. After a long period of continuous decline in area under paddy, it increased from 2.29 lakh ha to 2.34 lakh ha in 2008-09 and 2.54 lakh ha in 2009-10. It was due to the weightage given by the Govt. of Kerala as a part of food security.

The decadal trend in paddy area has also established that the decline was phenomenal (Fig. 5.5), though it steadily increased from 1951-60 (7.63 lakh ha) to 1971-80 (8.50 lakh ha). Thereafter there was a sharp decline and reached to its lowest (2.71 lakh ha) in 2001-09. The tri-decadal area under paddy also declined from 811600 ha to 469600 ha registering a decline of 42 per cent.

Accordingly, the rice production also increased from 1951-60 (8.94 lakh tonnes) to 1971-80 (13.04 lakh tonnes). Thereafter, there was a sharp decline in rice production from 11.68 lakh tonnes in 1981-90 to 6.28 lakh tonnes in 2001-09 (Fig. 5.5). Tri-decadal production has declined by 19 per cent from 1951 -80 (11.18 lakh tonnes) to 1981-09 (9.07 lakh tonnes).

Fig. 5.5 Trends in decadal and tri-decadal area, production and productivity of rice in Kerala from 1952-52 to 2008-09

While area and production of paddy was declining, productivity was increasing over a period of years. The productivity has increased by 155 per cent from 1952-53 (973 Kg/ha) to 2009-10 (2483 kg/ha). The highest productivity (2712 Kg/ha) was recorded during 2006-07, followed by 2008-09 (2520 Kg/ha). Inter-annual fluctuations in productivity are mostly attributed to the effect of floods. The reason for the gradual increase in productivity could be attributed to the adoption of modern agricultural practices along with the impact of various governmental schemes for the increase of rice productivity in the State. As evident from the annual productivity, decadal productivity also was gradually increasing. The productivity during 1951-60 (1145 Kg/ha) has increased to 2316 Kg/ha in 2001-09. The tri-decadal productivity from 1951-80 (1371Kg/ha) to 1981-09 (2011 Kg/ha) has increased by 47 per cent.

The present demand of rice in Kerala is 40 lakh tonnes and current level of production is just 6-7 lakh tonnes only. There exists a large gap between demand and production, having a shortage of about 85 per cent (Fig. 5.6).

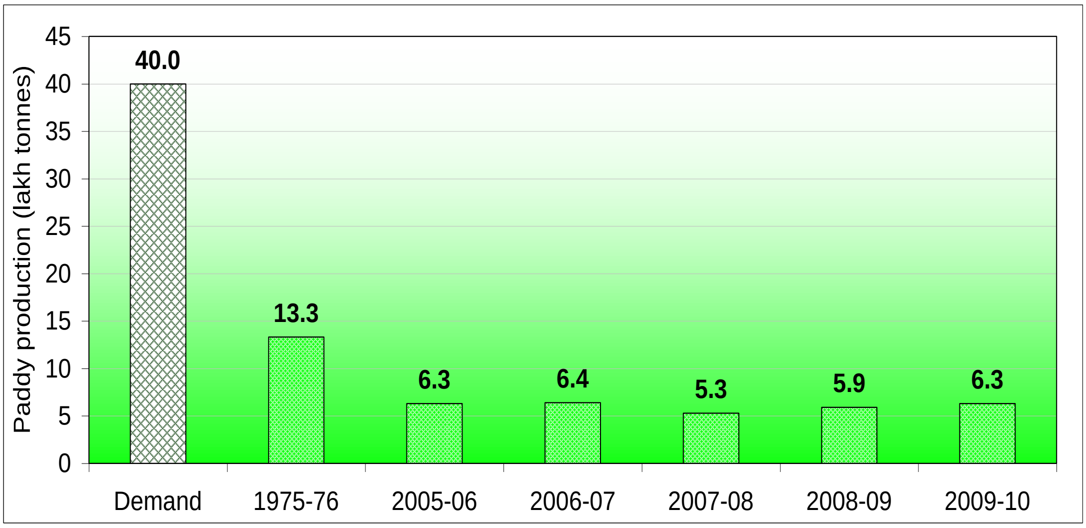


Fig. 5.6 Rice-demand and production in Kerala

There was a shortfall of more than 1.0 lakh tonnes in 2007-08 (5.28 lakh tonnes) due to unusual summer rains during the harvest season in Kuttanad and *Kole* lands in addition to prolonged rainy season in 2007. The effect of prolonged rains in 2007 and unusual pre-monsoon showers on rice production was brought out in detail in section 5.6

5.5 IMPACT OF HEAVY RAINFALL ON PADDY PRODUCTION IN KERALA

To understand the effect of heavy rainfall on paddy yield, the production data of paddy from 1952 - 53 to 2009 -10 were collected and examined. Heavy rainfall years were identified. A year is termed as a heavy rainfall year if the rainfall departure is more than 25 per cent of the long period average (LPA). The long period average of monsoon rainfall over Kerala is 1924.9mm. Based on the monsoonal rainfall, 13 heavy rainfall years were identified in Kerala. 1878 (2925.4 mm), 1882 (2652.9 mm), 1897 (2567.2 mm), 1907 (2594.7 mm), 1923 (2666.0 mm), 1924 (3115.4 mm), 1946 (2445.4 mm), 1947 (2435.9 mm), 1961 (2943.4 mm), 1968 (2609.4 mm), 1975 (2521.6 mm), 1981 (2526.4 mm) and 2007 (2470.7 mm) were the heavy rainfall years. Out of the 13 heavy rainfall years 1924, 1961 and 2007 were the very heavy rainfall years. In addition to the above classification, heavy rainfall received for few hours to days locally may lead to flash floods. Such floods also devastate the paddy fields, which could not be categorized under the heavy rainfall years because they don’t fall under the overall definition of a heavy rainfall year. Whenever heavy rainfalls were noticed during monsoon, the paddy production in the State of Kerala was adversely affected (Fig.5.7).

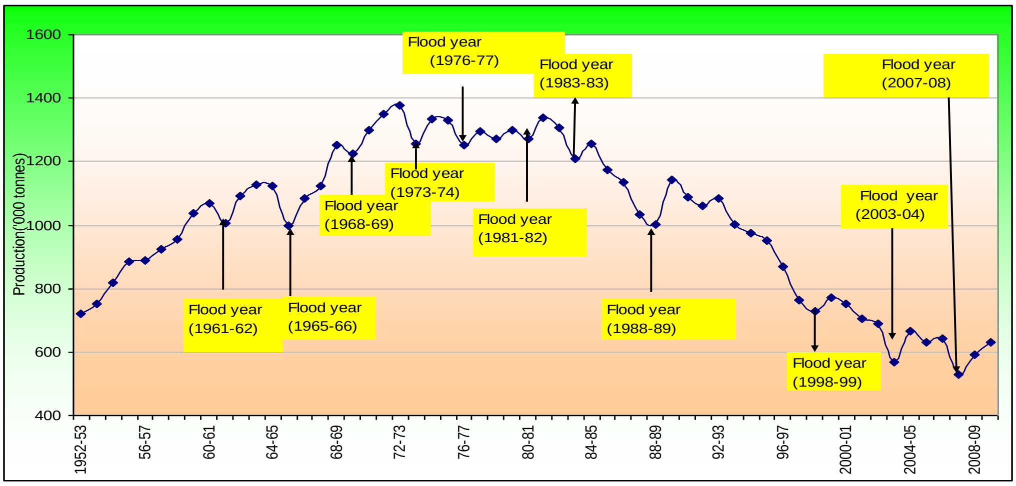


Fig. 5.7 Impact of heavy rainfall on rice production in Kerala

The decline in paddy production varied between 2 to 17.6 per cent due to heavy rainfall (Table 5.5). On an average, the effect of heavy rainfall on paddy production was 8.5 per cent, having the least effect in the year 1968 (2.0 per cent), followed by 1981 (2.1 per cent) and 1983 (2.4 per cent) while the highest damage due to floods was seen in recent years in 2007 (17.6 per cent) and 2004 (17.3 per cent).

Table 5.5 Effect of heavy rainfall on paddy production in Kerala from 1952-53 to 2009-10

Heavy rainfall	Paddy production (lakh tonnes)	% decline in paddy production due to heavy rainfall over the previous year
1961	10.0	6.0
1965	10.0	11.0
1968	12.5	2.0
1973	12.6	8.6
1976	12.5	5.8
1981	12.7	2.1
1983	12.1	2.4
1988	10.0	8.9
1998	7.7	12.2
2004	5.7	17.3
2007	5.3	17.6
Average% decline		8.54

The high percentage decline in 2007 was due to floods that were noticed during *kharif* 2007 and at the time of harvest of second crop in Kuttanad and Kole lands due to pre-monsoon showers in March 2008.

In the case of paddy productivity also, the effect of heavy rainfall was evident. Paddy productivity was adversely affected when there was a heavy rainfall event, except in 1988 during which the productivity did not show a decline (Fig. 5. 8).

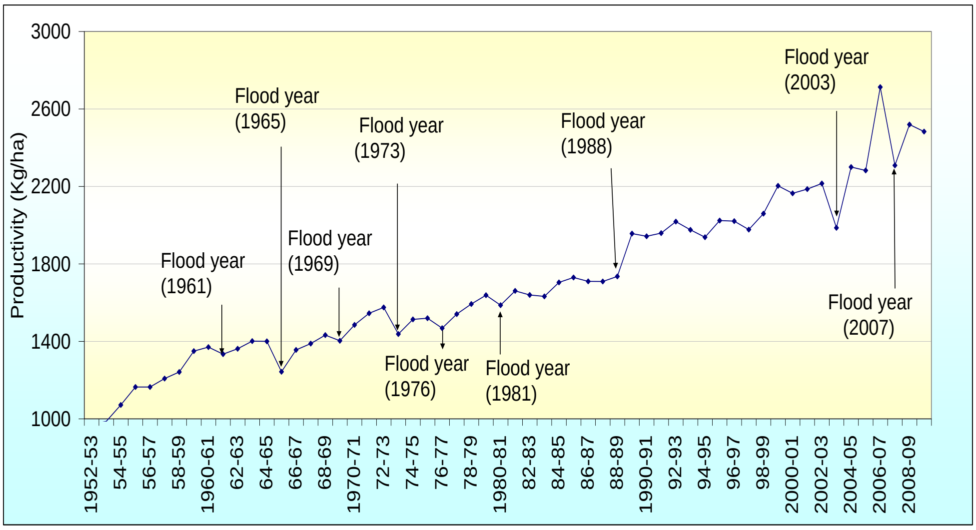


Fig. 5.8 Impact of heavy rainfall on rice productivity in Kerala

The decline in productivity varied between 1.3 to 14.9 per cent due to floods (Table 5.6)

Table 5.6 Effect of heavy rainfall on paddy productivity in Kerala from1952-53 to 2009-10

Heavy rainfall years	Paddy productivity (Kg/ha)	% decline in paddy productivity due to heavy rainfall over the previous year
1961	1334	2.7
1965	1243	11.2
1968	1403	2.0
1973	1438	8.7
1976	1468	3.4
1981	1639	1.3
1983	1632	0
1988	1735	1.5 (increase)
1998	1977	2.2
2004	1986	10.4
2007	2308	14.9
Average% decline		5.0

On an average, the effect of heavy rainfall on paddy productivity was 5 per cent, having the least effect in the year 1981 (1.3 per cent) while the highest damage due to heavy rainfall was seen in the recent year 2007 (14.9 per cent) and 2004 (10.4 per cent). Interestingly, the productivity did not change during 1983 due to heavy rainfall while there was a marginal increase of 1.5 per cent due to heavy rainfall in 1988.

As in the case of effect of drought on Indian foodgrains production, the effect of heavy rainfall on paddy production and productivity are clearly brought out. The rate of increase in productivity was adversely affected by the occurrence of heavy rainfall. For example, decline was seen in 1966-70 (0.6%), 1976-80 (2.7%), 1981-85 (6%), 1986-90 (7.5%), 1996-00 (4.6%) and 2001-05 (5.5%) as against the normal of 7.5 per cent (Fig. 5. 9). All the above pentads were witnessed floods during the crop growing season. It is evident that the decline in productivity is due to the effect of heavy rainfall on paddy during the crop growing season viz., *virippu*. While the effect of droughts on Indian foodgrains production could be reduced due to the technological interventions, the effect of heavy rainfall on paddy production can also be mitigated to some extent based on pro-active measures for sustenance of paddy yields.

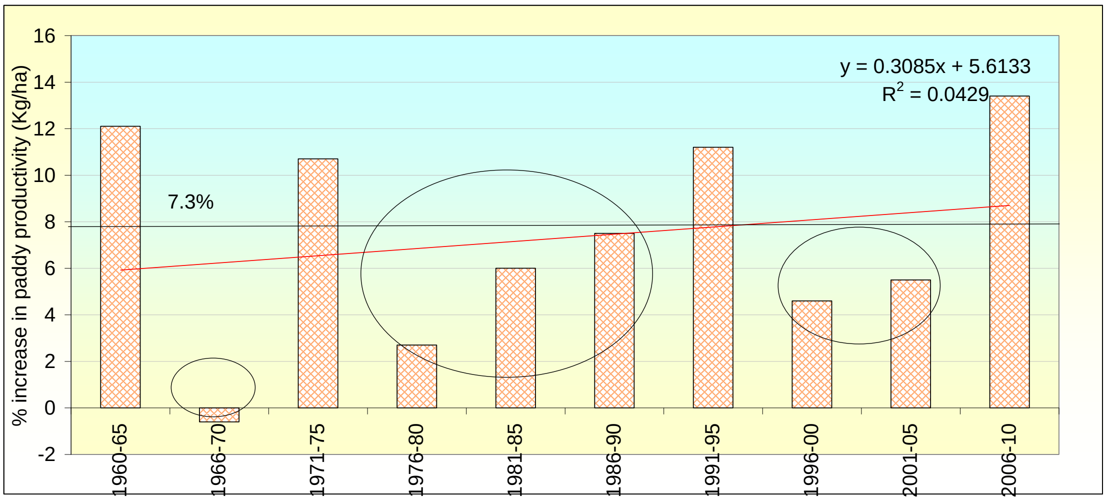


Fig. 5.9 Rate of percentage increase in paddy productivity in Kerala

5.6 EFFECT OF UNUSUAL SUMMER SHOWERS ON PADDY PRODUCTION IN KERALA DURING 2007-08

The monsoon behaviour in 2007 was totally different to that of previous years and heavy rains were noticed from June to September, led to floods in low lying areas. The paddy crop in Kuttanad belt was flooded and the final crop productivity as well as production was less. The average yield of paddy in farmers' fields of Kuttanad, which is one of the rice bowls of Kerala, was only 3.0 t/ha as against the expected harvest of 5.0 t/ha. Out of 9,118 ha of total cultivated land, 5623 ha of paddy was damaged in the Alappuzha belt of Kuttanad alone in *kharif* 2007 due to floods. The prolonged rains also led to delay in '*puncha*' sowing (second crop). The high acidic nature and salinity of the Kuttanad soil were intensified due to floods and bund breaches during monsoon season. To add to this monsoon fury, the unusual summer rains from 13-23rd March, 2008 also devastated the paddy production to a considerable extent in Alappuzha District and *Kole* lands of Thrissur District. The summer showers during March, 2008 coincided with harvest season of paddy. The harvested paddy and paddy fields under harvest were flooded. Due to wetness and flooding, the paddy germinated and the loss was heavy (Plate 5.1). More than one lakh tonnes of paddy were lost during 2007-08 due to occurrence of floods and unusual summer rains (Fig.5.10), accounting for 17% loss of grain yield. It was estimated that Rs.100/- crore was the loss due to damaged paddy.

Plate 5.1 Germinated paddy seeds in fields subsequent to unusual summer showers during March, 2008

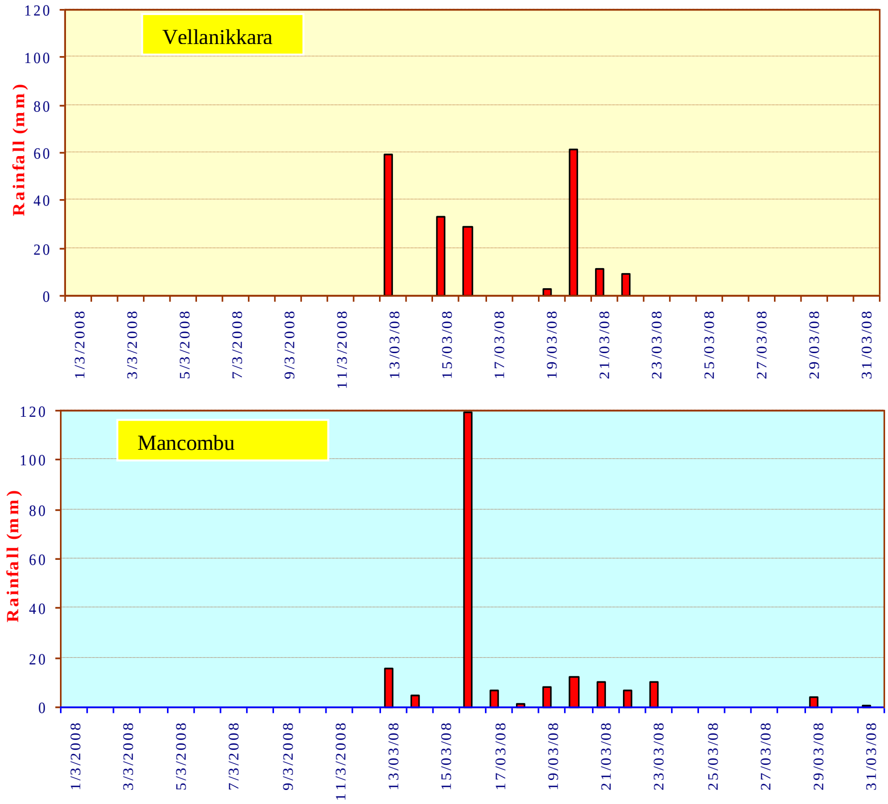


Fig.5.10 Effect of unusual summer showers on paddy production

5.7 EFFECT OF MONSOON UNCERTAINTIES ON RICE PRODUCTION DURING 2009

The actual monsoon rainfall was received in the State of Kerala only after 6th June though the onset of monsoon was on 23rd May in 2009. The month-wise departure of rainfall showed that during June and August the deficits were of the order of 36.6 per cent and 28.2 per cent from the normal, respectively (Table 5.7). As these months coincide with the major sowing/transplanting and reproductive phase of paddy in the State, a meteorological drought like situation was created. The occurrence of meteorological droughts or dryspell during reproductive and ripening phases may not conducive, which in turn, will help for low productivity of paddy. The occurrence of meteorological droughts or dryspells during June, July and August delayed the transplanting of paddy due to non-availability of standing water. Out of 14 districts, Thiruvananthapuram, Kollam, Pathanamthitta, Kottayam and Wayanad received below normal rainfall with deficits ranging from -19 to -33% as on 23 September 2009.

Table 5.7 Month-wise rainfall distribution during monsoon 2009 in Kerala

Month	Actual rainfall (mm)	Normal rainfall (mm)	Percentage departure in rainfall
June	433.6	683.6	-36.6
July	927.5	636.9	45.6
August	270.3	376.6	-28.2
September	327.6	228.4	43.4

As per the definition of the meteorological drought, Thiruvananthapuram and Wayanad were the only two districts categorized under “moderate”. Though the drought was categorized as “moderate” in the above two districts based on cumulative rainfall, in reality “severe” drought conditions persisted based on week-to-week rainfall deficits. Out of 12 weeks as on 19 August 2009, 9-10 weeks were categorized under the meteorological drought in Thiruvananthapuram and Kollam districts (Figs.5.11a and b).

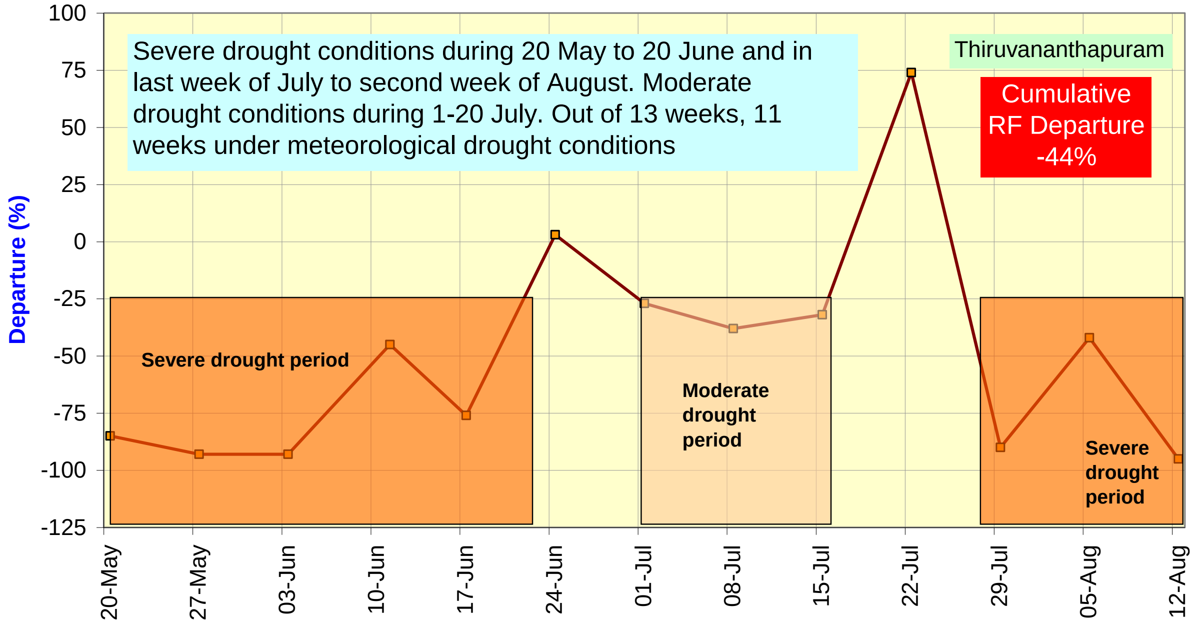


Fig.5.11a Weekly rainfall departures and drought situation in Kerala – Thiruvanthapuram district

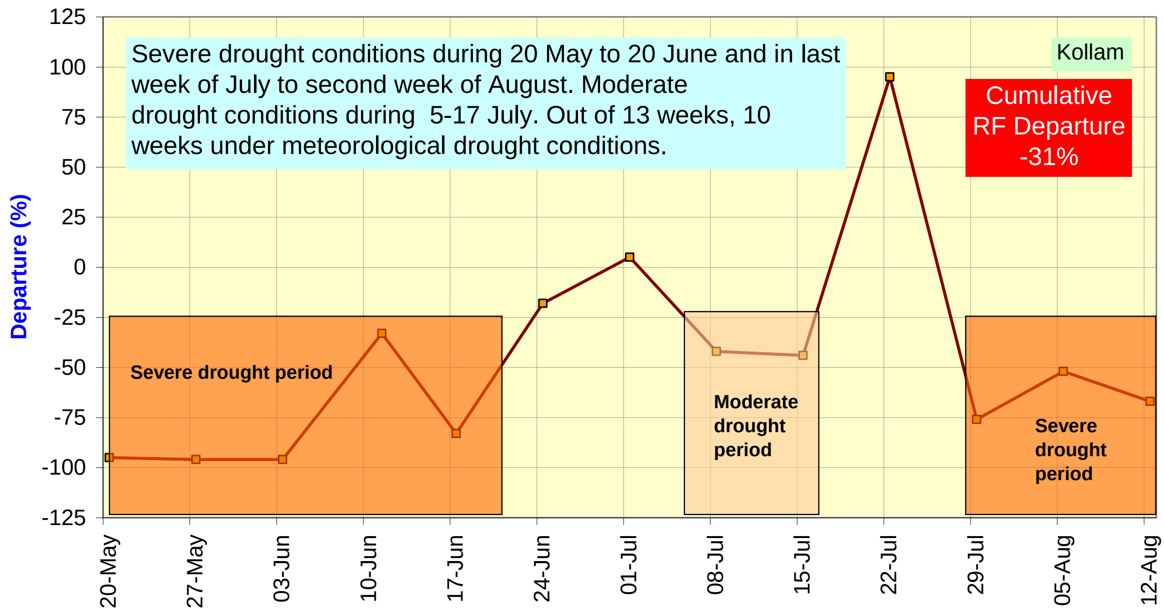


Fig.5.11b. Weekly rainfall departures and drought situation in Kerala - Kollam District

Severe drought conditions existed from 20 May to 20 June and also in the last week of July. In *Kharif (Virippu 2009)*, there was reduction in paddy area by more than 20% and undue delay in transplanting was noticed due to occurrence of severe and moderate droughts. It was estimated that an area of 20613 ha of paddy land is left as fallow due to the severe water stress/deficit rainfall in the State especially due to the lull phase of monsoon during the onset/strengthening phase (Table 5.8). The late sown crop was strained with very severe weed problems in many paddy fields. Lack of sufficient water has also reduced the fertilizer application to the extent required by the crop under rainfed conditions.

Table 5.8 Reduction in paddy due to water stress during June-July 2009

Sl.No.	District	Target (ha)	Coverage (ha)	Reduction in area coverage (ha) due to deficit rainfall & drought (20% of targeted area)
1	Thiruvananthapuram	1723	1350	344.6
2	Kollam	1889	1318	377.8
3	Alappuzha	955	130	191
4	Pathanamthitta	216	8755	43.2
5	Kottayam	6392	3331	1278.4
6	Idukki	1243	494	248.6
7	Ernakulam	5650	5097	1130
8	Thrissur	6440	4768	1288
9	Palakkad	54302	46198	10860
10	Malappuram	2772	1744	554.4
11	Kozhikode	445	216	89
12	Wayanad	11058	1100	100
13	Kannur	5629	3723	1125.8
14	Kasaragod	4351	2796	870.2
TOTAL		103065	81020	20613

After the harvest was over, according to the Department of Agriculture the yield of paddy was 1.94 lakh tonnes, though the targeted production was 3.48 lakh tonnes from an area of 145 thousand ha. The targeted area could not be achieved in view of the vagaries in monsoon and farmers could go for only 79.26 thousand ha.

5.8 EFFECT OF PROLONGED RAINS DURING 2010 ON RICE PRODUCTION

The year 2010 was one of the wettest years globally and in terms of temperature increase, it was similar to that of 2005, which was known as the year of hurricanes. As far as India is considered, the year 2010 was the warmest year, followed by 2009. In the State of Kerala too, the monsoon was extended and rains received during northeast monsoon were very heavy and led to floods. It was one of the wettest years during northeast monsoon. An amount of 939.1 mm rainfall was obtained in 39 rainy days as against the normal rainfall of 485 mm in 23 rainy days (Table 5.9) in Kumarakom (Kottayam district), indicating that the length of rainy period was prolonged to December, causing damage to paddy crop, which was ready for harvest or at maturity stage. Similar was the case in Moncombu in Alappuzha district. In the case of Vellanikkara, Thrissur, an amount of 974.9 mm of rainfall were received in 31 rainy days as against the normal rainfall of 413.7 mm in 19 rainy days during October – December. It indicated that the rainfall received was excess by 136 per cent in Vellanikkara. All the districts recorded excess rainfall by the end of the December. Kannur recorded 113% excess, followed by Thrissur (108%), Ernakulam (95%), Pathanamthitta (87%) and Thiruvananthapuram (83%). The least increase was in Wayanad (18%), followed by Idukki (19%). Overall, the State received 67% excess rainfall since October by the end of the December 2010.

Table 5.9 Rainfall (mm) during post monsoon season at RARS, Kumarakom

Month	Normal rainfall (mm)	Post monsoon rainfall (mm) during 2010	% departure
October	291.0	585.0	101.0
November	159.0	269.4	69.4
December	35.0	84.7	142.0
Total	485 (21)	939.1 (39)	93.6

In an event, in Kottayam district, very high rainfall of 75 mm was reported within two hours. Downpour of such high intensity is often noticed in cloud burst. This resulted to heavy crop loss in that area. In the *kole* lands of Thrissur also, similar situation prevailed. Farmers were struggling to get rid of the difficulties in raising new nurseries in the event of damage caused to the already raised paddy. A total of 12, 475 ha of paddy area was affected as a whole in the State of Kerala during the first crop while 2335 ha of paddy nursery during the second crop (Plate 5.2).

Plate 5.2 Flooded paddy nursery in upper Kuttanad region due to prolonged post monsoon 2010

The districts of Alappuzha, Pathanamthitta and Kottayam was the worst affected in the case of paddy due to unusual excess rains from October to December (Table 5.10).

Table 5.10 District-wise area of paddy damaged due to excessive rains during October to December 2010

Sl.No.	District	Paddy nursery area (ha)	Paddy area (ha)
1.	Thiruvannathapuram	0	0
2.	Kollam	0	250
3.	Alappuzha	2142	4330
4	Pathananthitta	0	3688
5	Kottayam	0	3124
6	Idukki	0	225
7	Ernakulam	0	185
8	Thrissur	70	285
9	Palakkad	0	124
10	Malappuram	0	0
11	Kozhikode	0	0
12	Wayanad	27	264.6
13	Kannur	96	0
14	Kasaragod	0	0
	Total	2335	12475

Source: Department of Agriculture, GoK

The unusual rains extended even in December wreaked havoc on the paddy fields of Kuttanad where the entire crop was damaged in October-November rains. Kanakassery Padasekharam (128 acres), Valiyakari Padasekharam (240 acres), Meenapally Padasekharam (145 acres) were the areas mostly affected. The Ayyanadu Padasekharam spread over 1000 acres were devastated. It was estimated that due to the non-seasonal rains in October-December, 3190 hectares of matured paddy crop worth Rs.893.2 lakh was destroyed. The loss due to submerging of paddy was Rs.1497.44 lakh, according to the official estimate. A Central team was deputed to assess the crop loss due to prolonged rains in October-December 2010. The extended rainfall affected the harvesting of second crop and sowing of *puncha* crop in Kuttanad area.

5.9 IMPACT OF CLIMATE CHANGE ON RICE PRODUCTION IN KERALA

The climate change projections in terms of temperature indicate that the maximum temperature is likely to increase between 0.7°C and 1.03°C by 2050 at the current rate of increase while the minimum temperature by 0.17°C and 0.34°C. Such increase (0.34°C to 0.68°C) was seen in the case of mean temperature and the temperature range (0.51 to 0.86°C) by 2050 (Table 5.11).

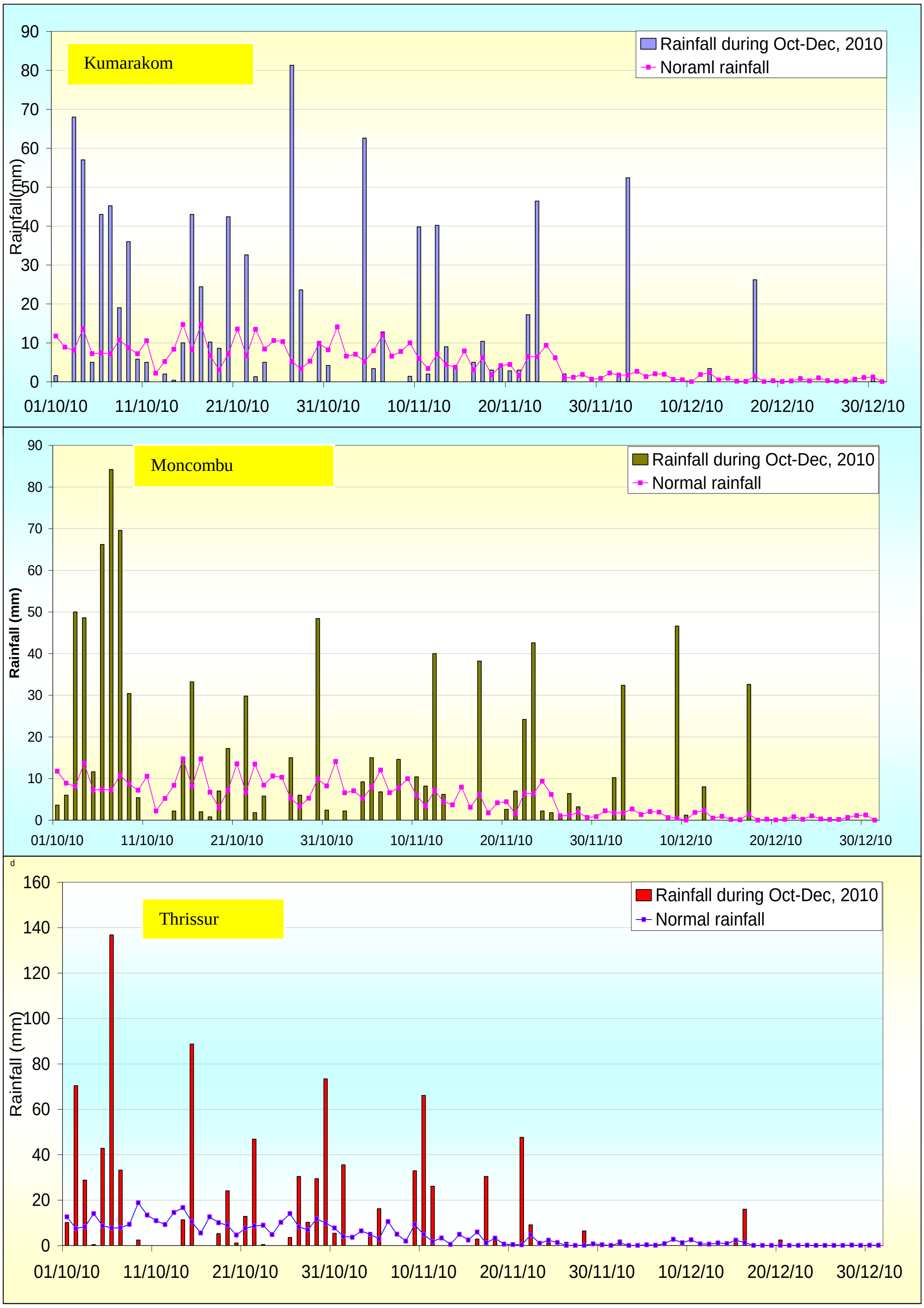


Fig.5.12 Prolonged post monsoon rainfall in Kumarakom (Kottayam), Mancombu (Alappuzha) and Thrissur during October – December 2010

Of course, the rate of increase in temperature depends upon the levels of GHGs, in particular CO_2 level in the atmosphere, as it is the major GHG, which contributes 70-75 per cent increase in temperature.

Table 5.11 Projections of increase in temperature (°C) over Kerala

Period	Temperature (°C)							
	Max T - S	MaxT- L	Min T- S	Min T- L	Mean T- S	MeanT -L	Range- S	Range- L
2010	0.72	1.08	0.22	0.28	0.47	0.68	0.51	0.80
2025	0.27	0.40	0.07	0.13	0.13	0.27	0.20	0.34
2050	0.70	1.03	0.17	0.34	0.34	0.68	0.51	0.86
2080	1.21	1.78	0.29	0.59	0.59	1.19	0.89	1.49
2100	1.55	2.28	0.38	0.76	0.76	1.52	1.14	1.91

S-State; L- lowlands

The crop simulation studies conducted in and around the country revealed that reduction in paddy yield is 5-7 per cent for an increase of 1°C in mean daily temperature. Reports from IRRI, Philippines reveal that 10 per cent reduction in yield is noticed for a temperature increase of 1°C. Warming nights due to increase in minimum temperature are likely to adversely affect rice yield. If that is the case, rice production is likely to be reduced by 5-10 per cent by 2050 and further down in 2080 and 2100 AD in the State of Kerala as per the crop simulation models.

There was an increase in rice productivity from 1.15 t/ha during the decade 1951-60 to 2.3 t/ha during the decade 2001-09. Though the rice production was declining over a period of time, the increase in crop productivity in the case of rice is evident due to introduction of better varieties with crop management and crop protection measures. It is the reason why, the tri-decadal rice productivity indicated that it was in increasing trend from 1.37 t/ha to 2.01 t/ha though the increase in temperature was evident in tune with the global warming (Figs. 5.13 & Fig.5.14).

Fig. 5.13 Decadal and tri-decadal changes in rainfall, aridity index, moisture index and number of droughts

Fig. 5.14 Decadal and tri-decadal changes in temperature along with rice productivity over Kerala

It suggests that the crop yields can be sustained and there may not be any decline in crop yield due to long period changes in temperature. The rate of increase in maximum temperature was 1.09°C while minimum temperature 0.28°C and the increase in mean temperature was 0.68°C across the low lands of Kerala, where paddy is cultivated mostly. At the same time, the inter annual / seasonal variations were noticed in rice production and its productivity due to weather aberrations in the form of climate variability such as floods during the first crop season, that is v*irippu.* Of course, the frequency of occurrence of weather abnormalities is likely to increase under the projected climate change scenario. Under such conditions, the rice yield is bound to decline. Therefore, the study indicates that the rice yields in Kerala are unlikely to decline due to long term climate change such as increase in temperature, but bound to decline to some extent through the abrupt short term changes as noticed in 2008, 2009 and 2010 in the form of monsoon uncertainties, led to short period droughts and floods.

Under the projected climate change scenario, monsoon uncertainties are expected in the State of Kerala on which rice production is dependant to a large extent. As already seen, prolonged post monsoon rains with unusual summer rains in the form of floods is a threat to paddy production: there was a decline of 8.5 per cent on an average, ranging from 2 to 17 percent depending upon the stage of crop coinciding the occurrence of floods. Therefore, abrupt increase in temperature and monsoon uncertainties are likely to influence the paddy production adversely in ensuing decades rather than the influence of climate change on long term basis. If that is the case, appropriate adaptation strategies are needed to cope up with the abrupt increase in temperature and heavy rains. Rice varieties suitable to withstand high temperature and salinity are to be evolved with various agro-techniques for sustenance of paddy production against ill effects of weather vagaries, expected to be more and more as a part of climate variability under the projected global warming and climate change.

5.10 IMPACT OF SOIL DEGRADATION ON RICE PRODUCTIVITY

A study conducted at the Regional Agricultural Research Station, Pattambi under the Kerala Agricultural University revealed that changes in climate are expected to create both positive as well as negative effect on rice yield. Yield decline was observed from 2004 to 2008 during *kharif* while the decline in yield was from 2003 to 2006 in the case of *rabi* season (Table 5.12). The reason for the yield reduction could be attributed to the delayed onset of monsoon and heavy rains during October/November which coincided with the harvest of *kharif* crop (Ilangovan *et al.,* 2011).

Table 5.12 Average yield of rice in *kharif* and *rabi* (t/ha)at Pattambi

Year	Kharif	Rabi
2000	4.93	3.48
2001	4.75	2.93
2002	4.04	3.14
2003	4.97	2.48
2004	3.97	1.94
2005	3.14	1.91
2006	3.67	2.27
2007	3.22	2.99
2008	3.70	2.58
Average	4.04	2.64

(After Ilangovan *et al.,* 2011).

The soil fertility status particularly, the phosphorus and potassium was degraded drastically due to varied weather over the period of years. The available P and K as reported in NARP Status Report Vol.II was 20 Kg/ha and 1476 Kg/ha, respectively. It was decreased to 12 Kg of P and 86 Kg of K during the year 2008. The removal of top fertile soil was prominent year after year leading to the decline in effective soil depth for rice cultivation. Hence, it can be concluded that apart from the effects of climate variability, the effects of degraded soil on crop production is an important component in deciding crop yields.

5.11 CLIMATE VARIABILITY AND FOOD PRICE

One of the reasons for the global food price increase is due to frequent occurrence of weather abnormalities like floods and droughts. The foodgrains production is not in tune with the demand whenever weather related disasters take place. The foodgrains production is stagnated overall since last 15 years as several parts of the world experienced floods and droughts or heat and cold waves. It was attributed to global warming and the nine warmest years was seen during the decade of 2001-10. In addition, it appears that some pieces of the land cultivable under foodgrains are shifted to bio-fuels across the world. It aggravated the availability of foodgrains, resulting in escalation of food price the world over. The crop loss varied between 40% and 90% in West African countries depending upon the severity of droughts in 2004-05.

World cereal output in 2005 fell due to adverse hot and dry weather, and drought that hit crops in parts of the European Union. Australia and other wheat growing countries suffered heavily in 2006 due to unprecedented drought, and the wheat production was only half of the mark in 2006 as against 20-25 million tonnes normally produced in Australia. India, Bangladesh, China and other countries in Southeast Asia, too suffered due to frequent floods and droughts since the last one decade, where rice is produced largely. Floods in Pakistan and China, cloudbursts in Leh, Ladakh region of Jammu and Kashmir, forest fires and heat waves in Russia during August 2010 and heavy rains in southern States of the Country from October to December due to depressions and cyclones were as a result of global warming and climate change. Forest fires and heat waves in Russia devastated thousands of hectares of wheat. As a result, cereal price escalated the world over. At the regional level, unusual summer rains in southern states of India resulted in heavy loss of paddy crop and vegetables during 2008. The price of both the commodities was very high locally. Similarly, extended rains and cyclones during northeast monsoon in southern states like Andhra Pradesh, Tamil Nadu and Kerala affected several crops adversely in 2010. The paddy crop was the worst hit. On an average, the current price of these food items is more by 50-70% when compared to prices in 2007. It was attributed to the impact of climate change. Even in 2007, prices were soaring due to scarcity of foodgrains the world over and more demand due to increase in population and their purchasing power.

On the one hand the farmers agitate for better price and on the other, consumers need to pay heavy price for food. This scenario becomes acute when weather related disaster takes place. Therefore, there is an urgent need to tackle the issue on a war-footing and to take steps for sustenance of foodgrains production and food security so as to stabilize food price under the projected climate change scenario. The projected climate change scenario indicates that the frequency of weather related abnormalities like floods, droughts, and heat and cold waves is likely to increase in ensuing years and food insecurity and escalation in food price are likely to persist if corrective proactive measures are not taken up by the various political governments to sustain foodgrain production against weather related disasters.

Chapter 6

Climate variability and plantations across the highranges

6.1 RAINFALL DISTRIBUTION

The mean annual rainfall across the high ranges of Kerala is 1901 mm, varying between 1865 mm at Pampadumpara and 1939 mm at Ambalavayal. The annual number of rainy days is 117. It is interesting to note that the number of rainy days did not show any significant difference between Pampadumpara and Ambalavayal. The monthly rainfall pattern at Pampadumpara (Idukki) and Ambalavayal (Wayanad) follows the same pattern. The distribution pattern of rainfall at Pampadumpara showed that the highest rainfall was received during July (365.3 mm), followed by June (295.6 mm), August (271.1 mm) and October (262.2 mm). The least was in February (14.8 mm), followed by January (18.7 mm). In the case of Ambalavayal, similar pattern was evident. The lowest rainfall at Ambalavayal was noticed during January (12.1 mm), followed by February (16.6mm) and December (24.3 mm). Both locations receive the highest rainfall in June, July, August and October due to the influence of both southwest and northeast monsoons (Fig. 6.1). Pamapdumpara receives relatively better rainfall from October to December when compared to that of Ambalavayal. It was attributed to the influence of northeast monsoon towards south of Kerala. It reveals that rainfall distribution across the cardamom tract of Kerala is bi-model, having a peak in July and another peak in October.

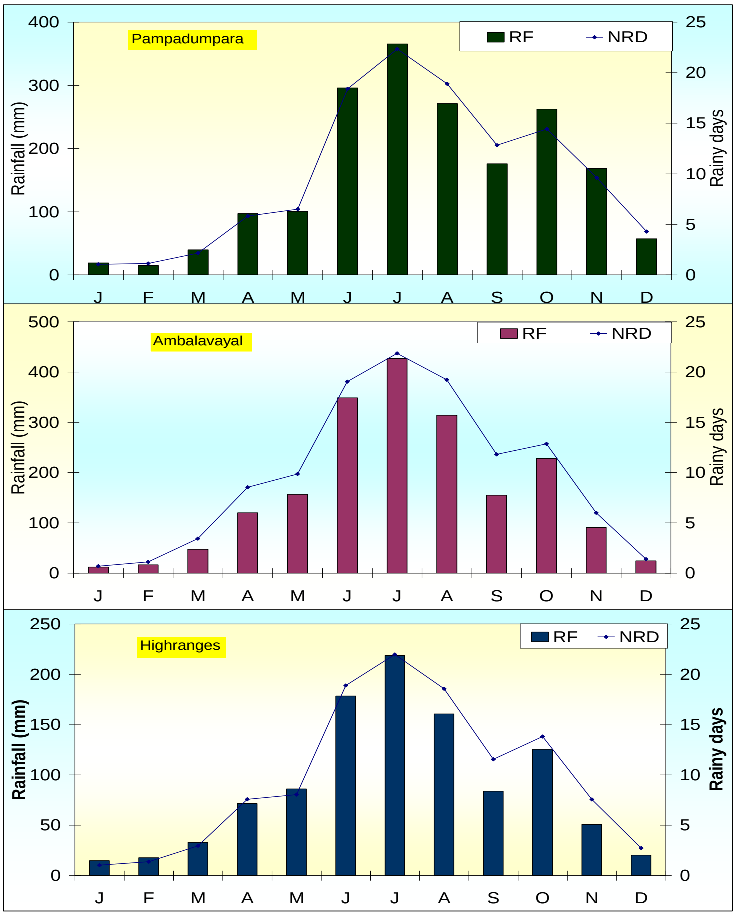


Fig. 6.1 Mean monthly rainfall and rainy days across the highranges

6.1.1 Rainfall trends

Trend analysis revealed that the rainfall across the highranges of Kerala is declining. Since southwest monsoon is the main rainy season in Kerala, the decline in rainfall during monsoon is a concern to the highranges. It revealed that post monsoon rainfall is increasing across the highranges in tune to the increase in post monsoon rainfall across the State as a whole. While Pampadumpara showed an increase in rainfall except during southwest monsoon, rainfall across Ambalavayal is declining (Table 6.1). The decline is more so since the last one and-a -half- decades.

Table 6.1 Trend in annual and seasonal rainfall (mm) across the highranges

Station	Rainfall trends				
	Annual	SWM	PM	Winter	Summer
Pampadumpara	+	-	+	+	+ *
Ambalavayal	- **	- **	+ **	- **	- **
Highranges	- **	-**	+**	-**	-**

* - significant at 5% level, ** - significant at 1% level,

6.2 THERMAL REGIME

The mean annual maximum temperature varied between 25.2°C and 27.2°C, and the annual mean minimum between 17.3°C and 17.7°C, respectively at Pampadumpara and Ambalavayal. Irrespective of the seasons, variations of minimum temperature at both locations across the cardamom tract of Kerala are relatively less when compared to that of maximum temperature. However, the diurnal changes in minimum temperature during winter are predominant and in the case of maximum temperature, the diurnal changes are predominant during summer. April recorded the highest mean annual maximum temperature at Pampadumpara (29.3°C), while it was in March (30.3°C) over Ambalavayal.

The lowest annual minimum temperature was recorded during December-January (15-16°C) across the highranges of Kerala. The annual range in temperature was high (9.5°C) over Ambalavayal while it was 7.7°C at Pamapdumpara. The maximum temperature during the rainy season (southwest as well as post monsoon) varied between 23 and 27°C, while the minimum between 17 and 18°C across the two locations. The range in temperature varied between 6 and 9°C. A gradual decline in temperature was noticed during winter from that of rainy season. The minimum temperature during this period across the cardamom tract is around 15-16°C and the temperature range shoots up to 9-13°C (Fig. 6.2). It is due to the fact that, maximum temperature showing a trend to shoot further up and minimum temperature to come down in the cardamom tract of Kerala.

The mean summer maximum temperature never crossed 30.0°C across the highranges while the range in temperature was high over Ambalavayal during summer (10.9°C) when compared to that of Pampadumpara (9.9°C). At the same time, the temperature range at Ambalavayal during summer was low (10.9°C) when compared to winter (12.1°C). Increase in maximum temperature and decline in minimum temperature resulted to increase in temperature range. It is a concern to the plantation crops grown across the highranges of Kerala in the context of projected climate change scenario.

6.2.1 Temperature Trends

The maximum temperature across the highranges was increasing irrespective of the seasons while the minimum temperature declined (Table 6.2). The mean temperature also showed an increasing trend except during summer. It is obvious that the range of temperature (the difference between the day maximum and the night minimum temperature) is increasing. Similar was the trend in the case of Pampadumpara.

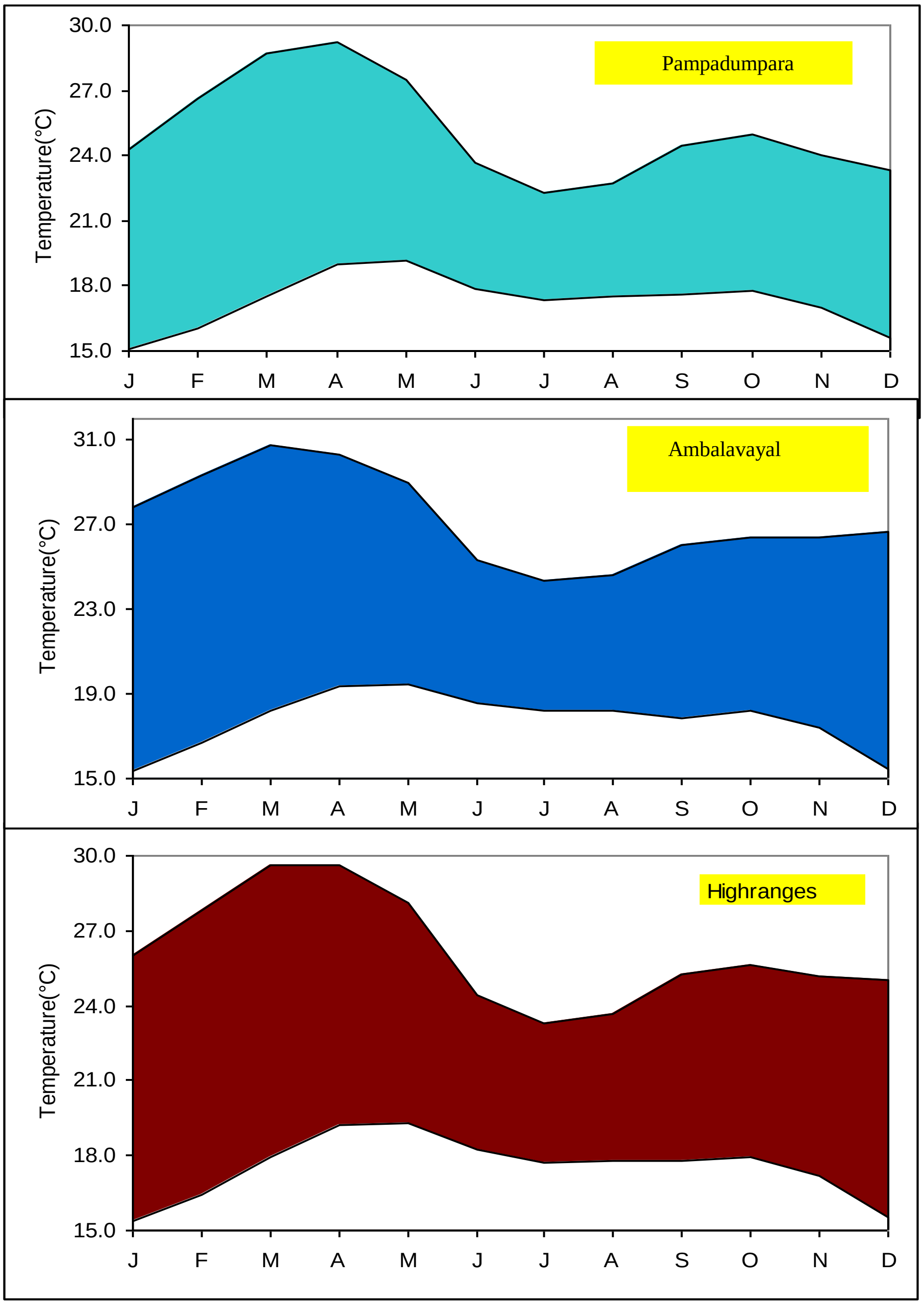


Fig.6.2 Thermal regime across the highranges

In the case of Ambalavayal (Wayanad), increase in maximum temperature is not seen as noted in the case of Pampadumpara, except a marginal increase in southwest monsoon. In the case of minimum temperature, it was increasing except during post monsoon.

Table 6.2 Trend in temperature (°C) across the highranges of Kerala

Maximum temperature (°C)		Pampadumpara (1978-2009)	Ambalavayal (1984-2009)	Highranges (1984-2009)
	Annual	+ **	- **	+ **
	SWM	+ **	+ **	+ **
	PM	+ **	- **	+ **
	Winter	+ **	- **	+ **
	Summer	+ **	- **	+ **
Minimum temperature(°C)	Annual	- **	+ **	- **
	SWM	- **	+ **	- **
	PM	- **	- **	- **
	Winter	- **	+ **	- **
	Summer	- **	+ **	- **
Mean temperature (°C)	Annual	+ **	+ **	+ **
	SWM	+ **	+ **	+ **
	PM	+ **	- **	+ **
	Winter	+ **	- **	+ **
	Summer	- **	- **	- **
Temperature range (°C)	Annual	+ *	- **	+ **
	SWM	+ **	+ **	+ **
	PM	+ **	- **	+ **
	Winter	+ **	- **	+ **
	Summer	+ **	- **	+ **

*- Significant at 5% level ** -Significant at 1% level

The mean temperature was increasing annually and during southwest monsoon while all other seasons showed declining trend. Unlike in the case of Pampadumpara, temperature range at Ambalavayal, exhibited a declining trend, except during southwest monsoon. It is worth mentioning the increase in temperature range across the high ranges as it may adversely affect the thermo - sensitive crops viz., cardamom, tea, coffee and black pepper. The increase in temperature range, therefore, is a concern across the highranges as it will impact adversely on the production of these crops (Rao *et al.,* 2008).

6.3 MOISTURE REGIME

The monthly moisture index at Pampadumpara varied from 388 per cent in July to -9.5 per cent in May. During the rainy months from June to

November, the moisture index was always above 100 per cent (Per humid A type climate). Soon after the rainy period, the moisture index all on a sudden fell down and the climate shifted to B1 humid type (Im=28.5 per cent) in December. In all the summer months from January to May, the moisture index was always below zero, ranging between -9.5 per cent in May to -41.3 in March, indicating that the moisture index during the above period were under the dry sub humid to arid type (Fig. 6.3).

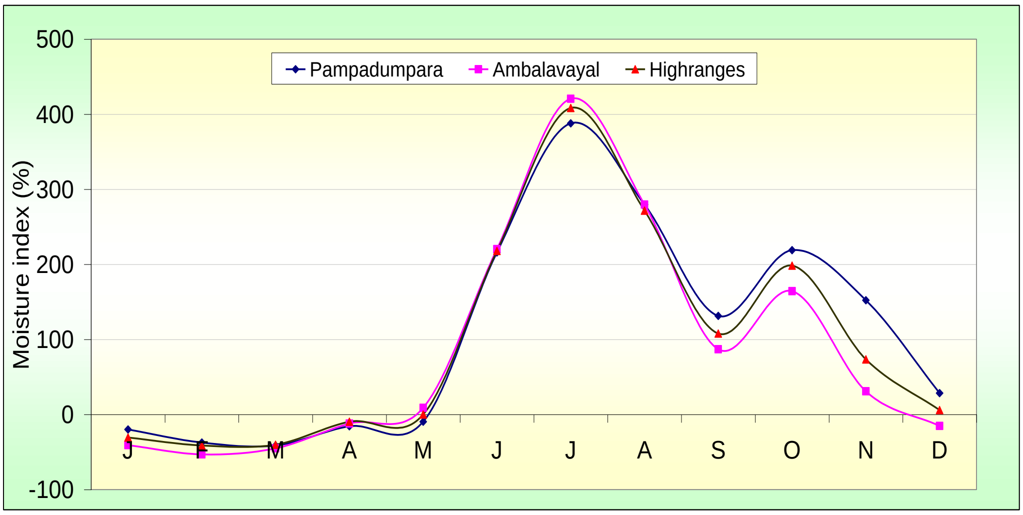


Fig. 6.3 March of monthly moisture Index (%) across the highranges

April and May fell under the dry sub humid as the moisture index was between -19 % to zero. January and February fell under Semiarid as the index was between -20 to -37.4 per cent. Only in March arid type climate was noticed, during which the moisture index was -41.3 per cent. In short, January to May, Idukki district experiences dry weather due to the non receipt of sufficient rainfall and hence the climate shifted from Perhumid during the rainy season to humid during the northeast monsoon. Thereafter the climate shifted from dry subhumid to arid during summer months as rainfall received was insignificant, if pre monsoon showers fail. Therefore, the monthly and seasonal climate shifts vary insignificantly. Similar was the trend in monthly climate fluctuations at Ambalavayal also. The moisture index varied between 420.6 per cent in July to -12 per cent in April. June, July, August and October only fell under the ‘per humid A’ type climate while September fell under ‘B4 humid type’ and November in ‘B1 humid’ climates.

It may be noted that though September and October coming under the rainy months in Kerala, in the Wayanad region these months are shifting towards drier climates within the humid B type. In contrast to Pampadumpara, at Ambalavayal, December fell under even lesser type humid regime (C1 dry sub humid). January, February and March clearly showed a tendency to move towards ‘Arid type (E)’ climate as the moisture index was always more than -40 per cent during the above months**.** As a whole, the highranges experience from ‘A’ perhumid climate to arid climate ‘E’ depending upon the rainfall distribution. Since the moisture index is predominantly influenced by rainfall, the index follows a similar pattern to that of rainfall.

During April and May, the moisture index fell under ‘C1 dry subhumid’ and ‘C2 moist subhumid’ type of climates. The fluctuations in moisture index at Ambalaval are more pronounced when compared to that of Pampadumpara as is evident from the analysis. Even during rainy months, moisture index showed a tendency to move towards lesser moisture regimes within the humid type climates (from B4 to B3 climate). Three months from January to March experience arid climate at Ambalavayal as against one (March) at Pampadumpara (Table 6.3). It reveals that Wayanad region of the Western Ghats in the highranges experience more dryspells during summer when compared to that of Pampadumpara.

6.3.1 Trend in climate shifts

The trend analysis indicated that annual moisture index across the highranges was declining. Annual moisture index at Pampadumpara was declining at the rate of 0.79 per cent per year while the declining rate was 0.67 percentages per year at Ambalavayal. As a whole, the decline of moisture index is at the rate of 0.65 per cent per year across the highranges. Decadal analysis also confirmed the above observations (Fig.6.4).

Table 6.3 Spatial distribution of monthly moisture index (MI) across the highranges

Month	Pampadumpara			Ambalavayal			Highranges		
	MI (%)	Climate types	Symbol	MI (%)	Climate types	Symbol	MI (%)	Climate types	Sym-bol
Jan	-19.9	Semiarid	D	-40.8	Arid	E	-30.6	Semi Arid	D
Feb	-37.4	Semiarid	D	-53.1	Arid	E	-41.2	Arid	E
Mar	-41.3	Arid	E	-45.1	Arid	E	-40.2	Arid	E
Apr	-15.7	Dry Sub humid	C1	-12.0	Dry Sub humid	C1	-9.6	Dry Sub humid	C1
May	-9.5	Dry Sub humid	C1	8.9	Moist Sub humid	C2	0.0	Moist Sub humid	C2
Jun	215.9	Perhumid	A	220.4	Perhumid	A	217.9	Per humid	A
Jul	387.8	Perhumid	A	420.6	Perhumid	A	408.3	Per humid	A
Aug	279.7	Perhumid	A	279.6	Perhumid	A	271.6	Per humid	A
Sept.	131.4	Perhumid	A	87.0	Humid	B4	107.9	Per humid	A
Oct	219	Perhumid	A	164.3	Perhumid	A	198.4	Per humid	A
Nov	152.2	Perhumid	A	30.9	Humid	B1	73.5	Humid	B3
Dec	28.5	Humid	B1	-15.1	Dry Subhumid	C1	6.0	Moist Sub humid	C2

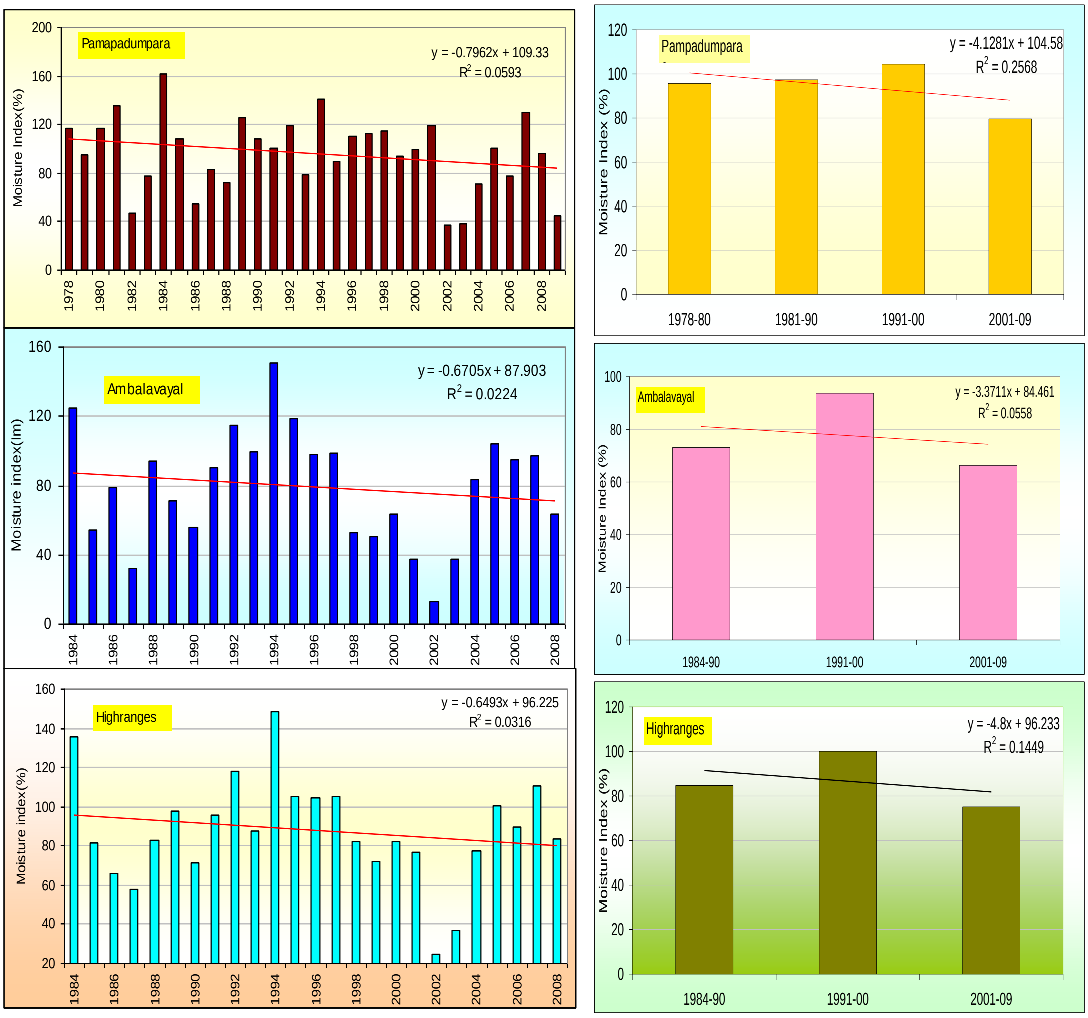


Fig. 6.4 Annual and decal trend of moisture index across the highranges

6. 4 TRENDS IN AREA AND PRODUCTION OF PLANTATIONS

6.4.1 Cardamom

The area under cardamom cultivation across the highranges of Kerala was increasing. The area under cardamom cultivation during 1952-53 was only 25.54 thousand hectares. It has increased and reached its peak during 1989-90 (64.55 thousand ha)

then declined and went down to 39.76 thousand ha during 2007-08. A sudden increase in area was noticed from 1965-66 (28.68 thousand ha) to 1966-67 (47.03 thousand ha). This might be due to the fact that more land area was brought under cardamom cultivation in Idukki district by planters as well as marginal farmers. The cropped area reached its peak during 1989-90 (64.55 thousand ha). Thereafter a sudden decline in area was noticed. It went down to 43.83 thousand ha in 1990-91. Thereafter area under cardamom did not show a sudden rise or fall. Long term production trend showed that it was increasing over a period of time. Since 1969-70, production was in increasing trend, though inter-annual variability is predominant in the case of production. The production was just 1.23 thousand tonnes during 1952-53. It has come up to 9.34 thousand tonnes in 2005-06 which has come down to 7.04 thousand tonnes in 2007-08 (Fig.6.5).

Decadal trend in area also showed a similar trend to that of annual. The maximum area under cardamom was noticed during 1981-90 (59.9 thousand ha), followed by 1971-80 (49.4 thousand ha) and the least in 1952-60 (28.0 thousand ha). Decadal production was gradually increasing over the decades. It has increased to 8.6 thousand tonnes during 2001-08 from the 1.3 thousand ha of 1952-60 (Fig. 6.6). As in the case of area and production, productivity of cardamom was in increasing trend on annual as well as decadal basis (Fig.6.7 & 6.8).

6.4.2 Tea

The area under tea has declined over the years. It has come down to 36400 ha in 2001-08 from 40400 ha in 1952-60 (Fig.6.5). The decline in area was gradual over the years. It revealed that the area under tea cultivation

was the lowest in 1981-90 (34.8 ha). It may be interesting to note that the 1981-90 was the warmest and driest decade over Kerala. Replacing the senile and unproductive plantations with young one, conversion of unproductive and uneconomical plantation area for non-agricultural purposes are some of the major reasons for decline in area under tea cultivation across the State. At the same time, tea production in the State has shown an increasing trend. A steady and gradual increase was seen over the years. It indicates that production has registered an increase of 67 per cent over the six decades. Production gradually increased from 34600 tonnes in 1952-60 to 57700 tonnes in 2007-08 (Fig. 6.6). As in the case of decadal production, decadal productivity was also increasing.

6.4.3 Coffee

Trend in area and production of Coffee in Kerala are towards increasing. During 1950s, the area under coffee cultivation in the State was only 12600 ha. Since then, coffee area exhibited a gradual increase over the years and it was about 85000 ha in 2007-08. Area under coffee registered substantial increase during the last two decades with an annual growth rate of over 2 per cent. The increase in production recorded during the period was much higher. Coffee provides opportunities for livelihood to nearly one lakh families including agricultural labourers. In Kerala, coffee is also one of the small holder plantation crops with nearly 76,000 holdings coming under the category with an average size of 2 ha.

It is noted that since 1990s, area under coffee has stagnated and it was revolving around 85000 ha. Production also gradually increased from 5110 during 1952-53 tonnes to 5925 tonnes in 2009-10 (Fig.6.5). Since 1990s, the highest coffee production of 7060 tonnes was recorded in 2000-01 followed by 2001-02 (6670 tonnes). Coffee production in the State in recent years was in declining trend.

Decadal analysis of area and production of coffee over the State shows that the area under coffee has not increased significantly (82-83 thousand tonnes) during the decades 1991-2000 and 2001-2008. At the same time, production has shown an increasing trend during the above period (Fig. 6.6). In tune to the increase in area and production, productivity of coffee in the State was increasing (Fig. 6.7 & 6. 8).

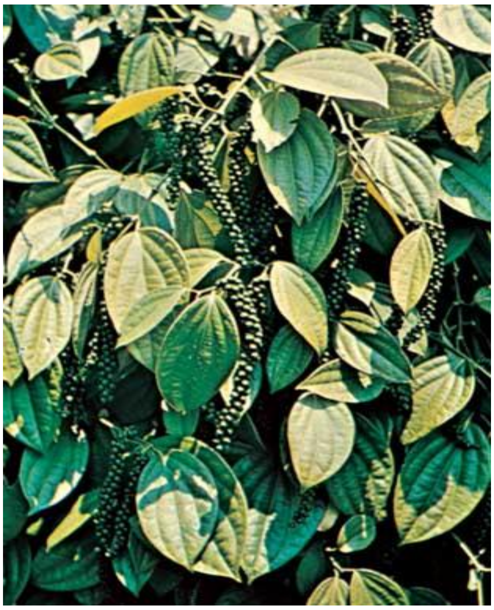
Kerala is the second largest producer of coffee in India. It produces 21 per cent of the total coffee out in the country. In Kerala, coffee is grown in an area of 84,976 ha of which 67,366 ha (79.4 per cent) and 84 per cent of production is from Wayanad district. It is interesting to note that Arabica coffee is very marginal in Wayanad district, the Coffee bowl of Kerala. Travancore and Nelliyampathy hills produce very small quantity of coffee (Table 6.4).

Table 6.4 Area and production coffee in Kerala during 2009-10

	Area(ha)			Production(MT)		
	Arabica	Robusta	Total	Arabica	Robusta	Total
Wayand	2 (0.0)	67364 (83.1)	67366 (79.4)	- (0)	49950 (86.3)	49950 (84.3)
Travancore	1909 (51.4)	10871 (13.4)	12780 (15.1)	775 (56.4)	6650 (11.5)	7425 (12.5)
Nelliyampathis	1800 (48.5)	2850 (3.5)	4650 (5.5)	600 (43.6)	1275 (2.2)	1875 (3.2)
Total	3711	81085	84796	1375	57875	59250

( )- figures in parenthesis indicate the percentage contribution to the total

6.4.4 Black pepper



In India, Kerala is the leading producer of black pepper accounting for more than 90%. Long term trend analysis showed that area and production of pepper in the state has been increasing (Fig.6.5). The data collected from the Directorate of Economics and Statistics, Govt. of Kerala revealed that the area under pepper cultivation in the State was just 78.8 thousand ha during 1952-53. It gradually showed an increasing trend until 1974-75 (118.4 thousand ha). Since then area declined all on a sudden and it was 108.3 thousand ha during 1975-76 and did not exhibit any increase for about one decade. From 1985-86 onwards, area under pepper cultivation increased slowly. It increased to 121.6 thousand ha in 1985-86 and reached to 253.04 thousand ha in 2007-08. In the case of production, it was just 22.63 thousand tonnes during 1952-53. The production was just 17.35 thousand tonnes during

1984-85, which was the lowest production received in any year. It crossed 30 thousand tonnes in 1986-86 and then gradually reached to 63.9 thousand tonnes in 2007-08. The highest (69.02 thousand tonnes) was noticed during 2002-04, followed by 1998-99 (68.5 thousand tonnes). Wide inter-annual variability could be observed in production as in the case of area. The lowest production was obtained in 1984-85 while the highest in 2005-06 (75.7 thousand tonnes). Continuous summer rainfall received during summer 1984 might have led to the lowest production of pepper during that year.

Decadal area in pepper showed a gradual increase from 1952-60 to 2007-08 (Fig. 6.6). It has increased from 87.4 thousand ha in 1952-53 to 230.1 thousand ha in 2007-08, registering an increase of 163.2 per cent over a period of 56 years. At the same time, production also showed an increase of 163 per cent during the same period. It increased from 25.7 thousand tonnes in 1952-60 to 67.6 thousand tonnes in 2001-08. There was a decline of 13 per cent in production during the decade 1971-80 over the previous decade 1961-70. The productivity of black pepper as in the case of cardamom, tea and coffee was in increasing trend (Fig. 6.7 & 6.8).

As a whole, the area under cardamom, coffee and black pepper across the highranges of Kerala was increasing while declining in the case of tea. Interestingly, all the four selected crops showed increase in production during the study period though inter-annual variations in plantation crops production and productivity was insignificant. Though increasing trend was noticed in plantation crops production and productivity during the study period, the decline in recent years is the concern. Similar was the decadal production trends in the case of cardamom, coffee and black pepper. In the case of productivity on decadal-wise, tea and black pepper showed declining trend while increase in the case of cardamom and coffee in the recent years from 2001 to 2008.

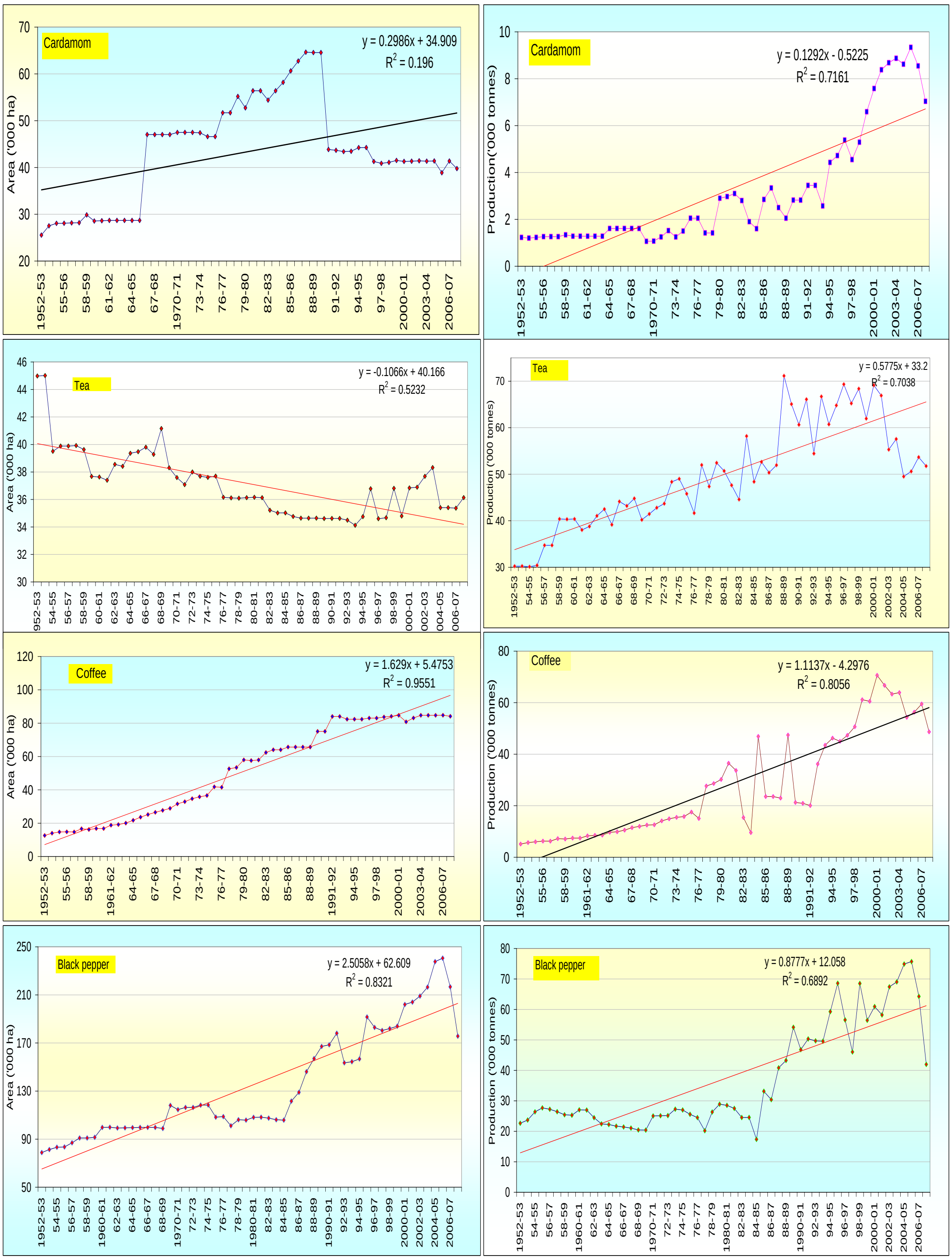


Fig. 6.5 Trends in area and production of plantation crops over Kerala

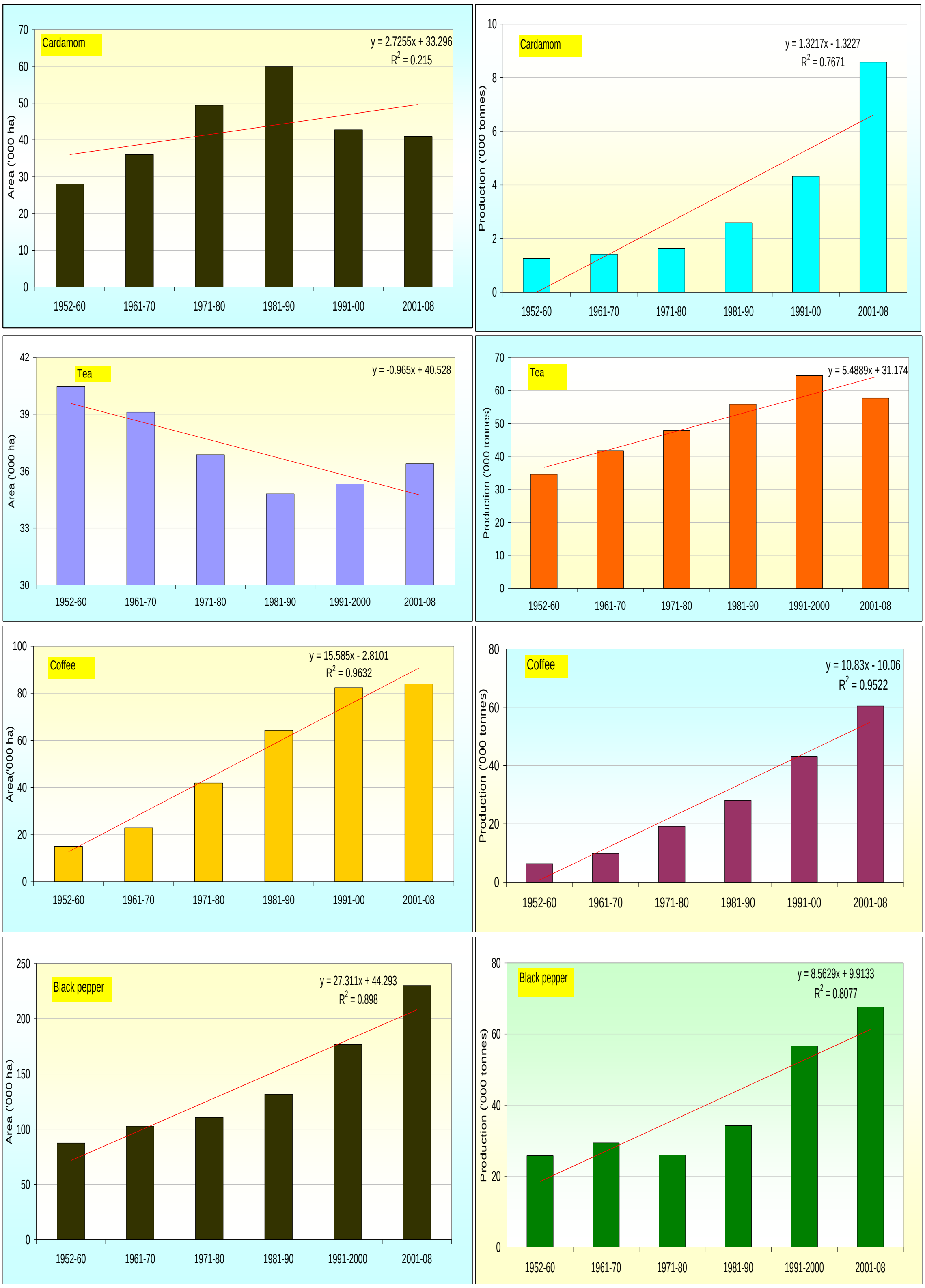


Fig.6.6 Decadal trends in area and production of plantation crops over Kerala

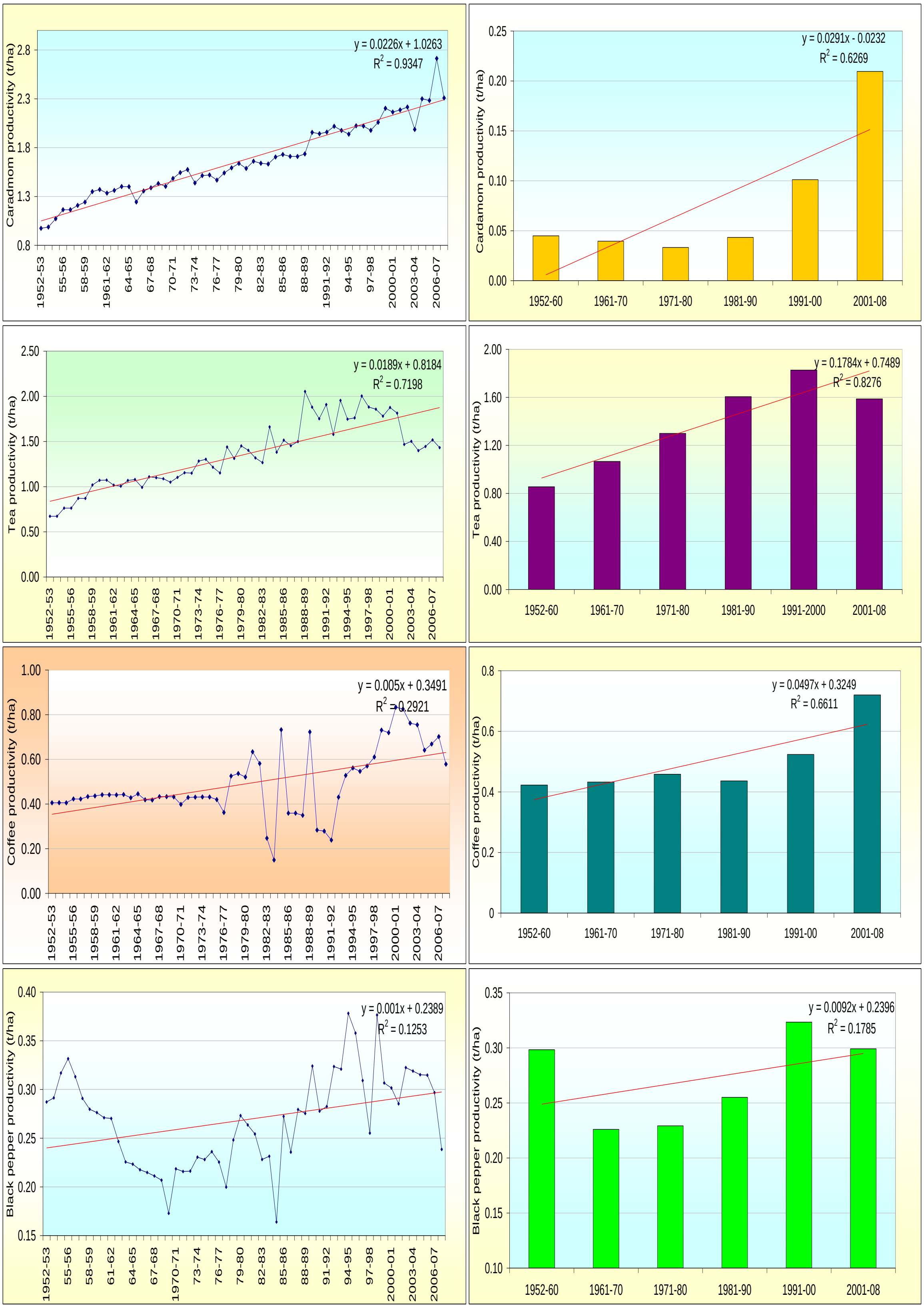


Fig.6.7 Trends in annual and decadal productivity of plantation crops over Kerala

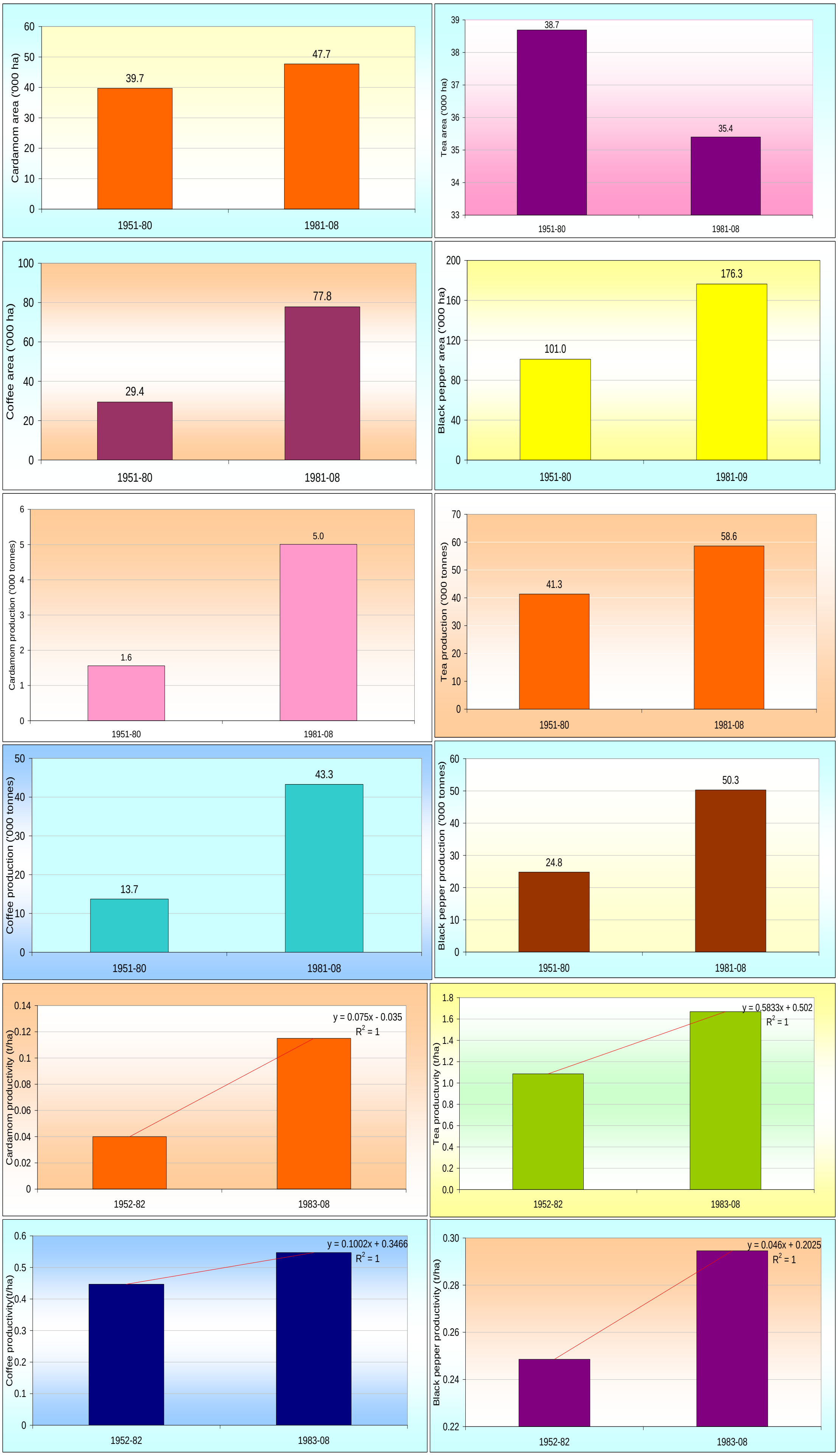


Fig. 6.8 Tri-decadal area, production and productivity of plantations

6.5 CLIMATE VARIABILITY AND PRODUCTION OF PLANTATION CROPS

6.5.1 Annual rainfall versus plantations

The influence of annual rainfall on all the four selected crops was negative indicating that the yield was low when the annual rainfall was high and vice versa. Of course, such trend was not seen always as seen in the case of tea since the relationship between rainfall and yield was seen in sixty per cent of the years (Fig. 6.9).

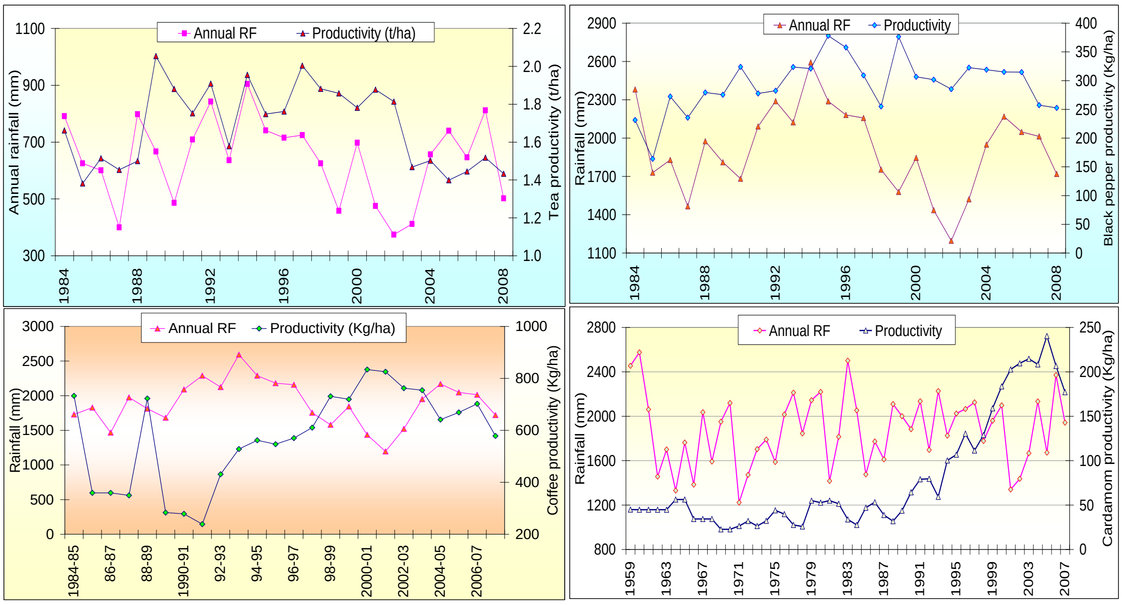


Fig.6.9 Rainfall and plantations

In the case of coffee, blossom and backing showers are very important. As seen, if any one them fails, the coffee yield is adversely affected. Of course, there was a negative relationship between high annual rainfall and coffee yields as seen in the case of tea. It was true in the case of black pepper also. Interestingly, both the crops coffee and black pepper respond differently to summer rainfall because it is good in the case of coffee as it requires blossom and backing showers between February/March and March/April while it is not so in the case of black pepper as it needs dry spell. In fact, it is not the dry spell needed to black pepper but continuous rains to complete its floral biology and berry formation and its development. Such environment lacks in the case of pre-monsoon showers during summer because the dryspell which follows after pre-monsoon showers adversely affects the floral biology and yield of black pepper is likely to be low under such a situation. However, both the crops responded negatively to high annual rainfall. Such is the trend in the case of cardamom also though from the data, it is not that much evident. However, cardamom respond positively to summer rainfall and yields well whenever summer rainfall is noticed. In the humid tropics like Kerala, which experiences high rainfall with prolonged wet spell may not be conducive as it results in low crop productivity. It is true in all the four crops tested. The low productivity in high rainfall years could be attributed to waterlogging, lack of aeration, low evapotranspiration, low sunshine hours and less intake of nutrients. In addition, high rainfall may lead to incidence of crop pests and diseases.

6.5.2 Rainfall and tea

The relationship between annual rainfall versus tea productivity indicated that the yield is influenced by rainfall in majority of the years. For example, the tea yield in 1985 was low (1.38 t/ha) when the rainfall was high (625mm), followed by 1.45 t/ha in 1987 (838 mm), 1.49 t/ha in 1988 (798 mm), 1.5 t/ha in 2004 (656 mm), 1.39 t/ha in 2005 (740 mm), 1.44 t/ha in 2006 (646 mm) and 1.5 t/ha in 2007 (811.6 mm) as against the normal tea yield of 1.7 t/ha. In contrast, the tea yield was high (2.1 t/ha) in the year 1989 when the annual rainfall was low (667mm). Such was the relationship in 1990, 1997 and 1999 during which the yield was 1.87 t/ha, 2.0 t/ha and 1.90 t/ha, respectively (*see Fig. 6.9*). Out of 25 years, the above relationship was found in 15 years, indicating that in 60 per cent of the years, there was a relationship between annual rainfall and tea yield. It revealed that tea yield was high when the annual rainfall was low and vice versa. Such relationship did not exist in

40 per cent of years. It is obvious that tea yield depends up on several other environmental factors. However, high rainfall is not conducive for tea yield which is true in many plantation crops under the topical humid climate like Kerala where monsoon rainfall is very high. The tea productivity is also declining in recent years since 1997 onwards irrespective of rainfall pattern. Heavy rainfall leads to soil moisture surplus and waterlogging, low evapotranspiration, low uptakes of nutrients and lack of aeration in the root zone. Prolonged rains may reduce the number of sunshine hours. In the case of tea, these factors are not conducive for better vegetative growth. In addition, it responded positively to availability of sunshine. That is the reason, why, the tea yield was low wherever the rainfall was high.

6.5.3 Rainfall and coffee

Rainfall seems to the most important factors among various weather elements influencing flowering and yield of coffee. Kannan *et al.,* (1987) observed that blossom showers of 20 - 40 mm during February -March and backing showers of 50-75 mm during March - April are considered to be critical for flowering and fruit set in Robusta coffee. Failure of any of these rains will lead to poor coffee yields. Ideal time for receipt of blossom showers for Robusta coffee is mid February to mid March. Delay in blossom showers beyond March would affect the fruit set. A blossom rainfall of about 20-40 mm received either in one day or in 2-3 consecutive days during ideal time (February-March) is adequate for inducing normal blossom in Robusta coffee. Inadequate blossom showers result in poor growth of flower buds leading to a condition called ‘pinking’ denoted by the pinking colour of the failed flower buds. Backing showers should be received within one month after the receipt of blossom showers. 70-75 mm of backing rains is desirable for normal retention of newly set fruits. Any delay or absence of backing showers also would result in drying up of newly set fruits and thereby affects the final yield.

It indicated that whenever the annual rainfall was high, coffee recorded poor yield as in the case of tea and vice versa. For example, annual rainfall was high in 1985-86, yield was low (0.36 t/ha), followed by 1987-88 (0.35 t/ha), 1989-90 (0.28 t/ha), 1991-92 (0.24 t/ha), 1994-95 (0.56 t/ha) and 1996-97(0.57 t/ha). In contrast, when the annual rainfall was low, productivity was comparatively high. For example, when the rainfall was low during 2000-01, the yield was high (0.83 t/ha). Similar was the case in 1997-98, 1998-99, 2005-06 and 2006-07 during which the yield was high.

In majority of the years (86 per cent) during the study period, the inverse relationship with annual rainfall was evident. It is true that annual rainfall do not have significant role in deciding crop performance, though it responds negatively. It is the blossom and backing showers which are critical to coffee yield. As in the case of many plantation crops, high annual rainfall is not conducive to coffee.

6.5.4 Effect of blossom and backing showers on coffee production

It was observed that during 1976 and 1983, there were no blossom showers either in February or March, which resulted to poor flowering in coffee growing tracts of Wayanad. The yield recorded during the ensuing crop season was 172 Kg/ha in 1976 and 315 Kg/ha in 1983 respectively (Fig.6.10). Similarly, comparatively poor yield (598 Kg/ha) was noticed during 2006 when no significant rains were seen received in February. At the same time, an amount of 85.4 mm of rains were received in March.

During 2000 also, no significant blossom rains were received during February and March which also led to comparatively poor yield (656 Kg/ha). The yield was comparatively higher in 1977, 1981 and 1984 during which the yield recorded was 684 Kg/ha, 753 Kg/ha and 811 Kg/ha, respectively. The years 2001 (802 Kg/ha), 2003 (739 Kg/ha), 2007 (705 Kg/ha) and 2008 (703 Kg/ha) also recorded comparatively higher yields when the blossom showers were received.

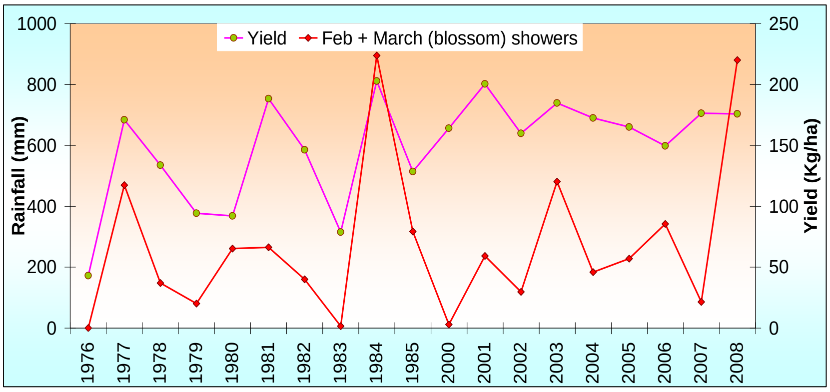


Fig. 6.10 Blossom showers and coffee yield at Ambalavayal

During all the above years, blossom showers were seen received during the critical periods (Feb-Mar), which resulted to better coffee yield. On critical examination of the rainfall data as well as yield, it was evident that better yield could be obtained even if the rainfall during February was scanty but make up with rainfall in March, as observed in 1981 along with backing showers. It is also true that if blossom showers are enough and no backing showers during April/May, the yield is likely to be less and vice versa (Table 6.5).

6.5.5 Rainfall and black pepper

In majority of the years (58 per cent), an increase in production was noticed in accordance with increase in rainfall. For example in 1986, 1988, 1992 and 2003 during which a hike in yield was noticed when the annual rainfall was high. Likewise a decrease in production was also noticed when the annual rainfall was low as noticed in majority of the years (46 per cent) during the study period. It showed that in majority of the years, there was a direct relationship with annual rainfall. It also revealed that high annual rainfall results to low yield in black pepper and vice versa. For example, high rainfall was recorded in 1984, 1991, 1992 and 2007 during which the black pepper yield was poor (231 Kg/ha, 278 Kg/ha, 282 Kg/ha and 257 Kg/ha, respectively). Similarly, when the yield was high in 1990 (324 Kg/ha), 1993 (324 Kg/ha), 1995 (378 Kg/ha) and 1999 (376 Kg/ha) the annual rainfall received was low (*see Fig.6.9*). It indicates that high annual rainfall adversely affects black pepper production. At the same time, better yields were recorded during years with low annual rainfall. In fact, in the case of black pepper, it is the distribution pattern of monsoon rainfall which determines the final yield. Continuous rainfall during the southwest monsoon season is good for better flowering and spike elongation and finally berry development. At the same time, the yield of black pepper was low in majority of the years when good summer showers were noticed during March and April

In majority of the years when good summer showers were received, yield of black pepper was low. The lowest yield of 105.8 Kg/ha was recorded in 1984. It was attributed to the receipt of continuous rains throughout the summer period. Even January and February months were not devoid of rains. In Wayanad District, moderate to heavy rains were received from January to May during 2004. This resulted to the poorest pepper production in the State. Similar situation prevailed in 1958, 1963, 1968, 1975, 1976 and 1977 (Fig.6.11). During these years, continuous rains during the dry months adversely affected the physiological process of black pepper prior to flowering and finally berry yields were poor (25.43, 22.42, 20.4, 25.58, 24.5 and 20.2 thousand tonnes, in 1958, 1963, 1968,1975, 1976 and 1977, respectively). There exists a strong negative relationship between rainfall during dry months and yield.

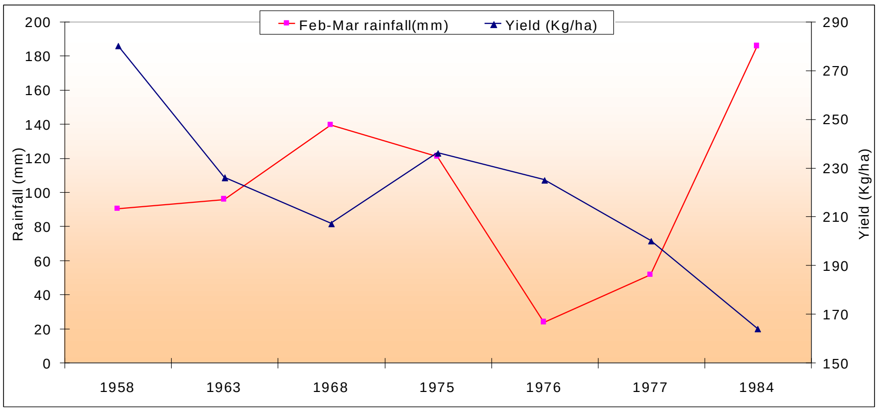


Fig. 6.11 Pepper yield over Kerala during years with good summer showers

Comparatively good yields were obtained during years when summer rains fail or were poor. For example, during 1992, 1998, 2002, 2004 and 2005, the berry yields was comparatively better since showers were less during the summer months (Table 6.6). There exists a strong positive relationship between pepper yield and poor summer showers.

Table 6.6 Yield of black pepper during years with poor summer showers

Year	Rainfall (mm) during			Yield ('000 tonnes)
	February	March	Feb. + Mar.	
1992	1	0	1	49.67
1998	2	13.3	15.3	68.51
2002	7.8	29.7	37.5	67.4
2004	8	36.2	44.2	74.9
2005	2.6	18.4	21	75.7

A dryspell or a drought before flowering period (June-July) is a pre-requisite condition for pepper plant before the commencement of flowering.

It may be noted that 1983, 1990, 1992 and 2004 were disastrous drought years in Kerala. Except in 1990, all the years recorded an increase in production, revealing that black pepper production is not affected even during disastrous drought years, to a certain extent while all other plantation crops production are adversely affected. The yield reduction in 1990 could be attributed to incidence of insect, pest and diseases. This reveals that drought/continuous water stress/long dryspells are not an adverse condition as far as pepper plants are concerned. At the same time, severe summer conditions with acute water stress coupled with high maximum surface air temperatures may devastate the young and senile pepper vines as reported in 2004 in Wayanad district. However, during 2004, no yield reduction is recorded in the pepper yield data of the State. The years 1961, 1967, 1979, 1986 also recorded comparatively better yields.

It reveals that ups and downs in the productivity curve are mostly attributed to the occurrence of summer showers during the critical periods of the crop (Fig.6.12). The receipt or non receipt of summer showers especially during March-April will determine the success or failure of black pepper. If the summer showers are good, pepper yield will be less and vice versa. In sub mountainous regions of Wayanad district, coffee and black pepper is planted as a mixed farming system as black pepper and coffee behave antagonistically to summer showers. That is to say, when one crop (coffee) is benefited with good yield on receipt of summer showers, the other crop (black pepper) yield will be adversely affected.

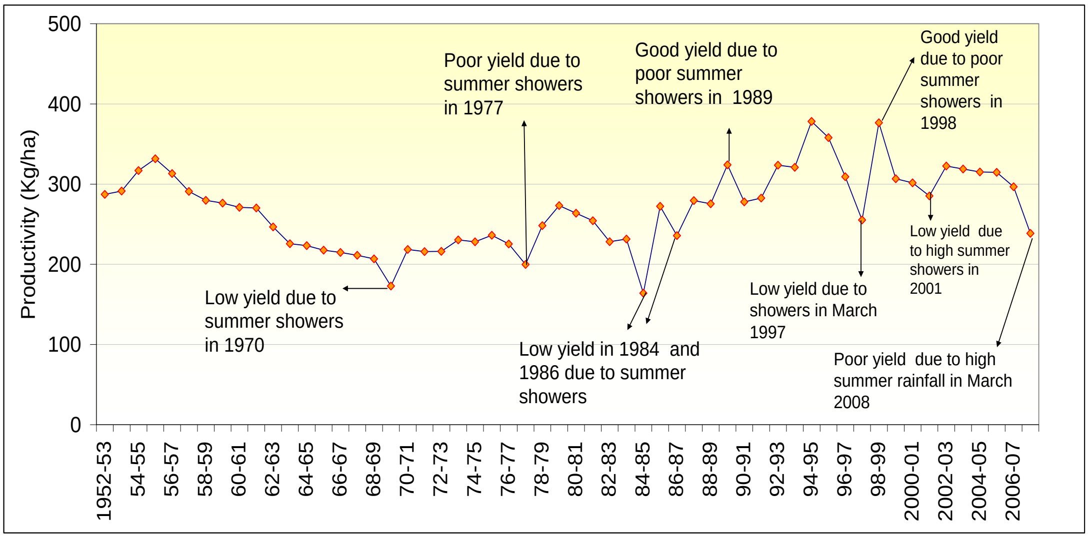


Fig. 6.12 Effect of summer rainfall on black pepper productivity

6.5.5.1 Effect of rainfall on the pepper production in Wayanad District

1984 was a year during which no drought situation prevailed as rainfall was received from January through May. An amount of 244.5 mm was received during March and April alone spreading in 26 days. This situation led to poor harvest in black pepper. The yield of pepper was only 185 Kg/ha while coffee yield was high during that year (811 Kg/ha). Similarly, during 2003 (285 Kg/ha) and 2008 (198 Kg/ha) good summer showers were received during March and April which resulted to poor pepper harvest (Fig. 6.13). The yield of coffee was comparatively better, 739Kg/ha and 703 Kg/ha, respectively in 2003 and 2008.

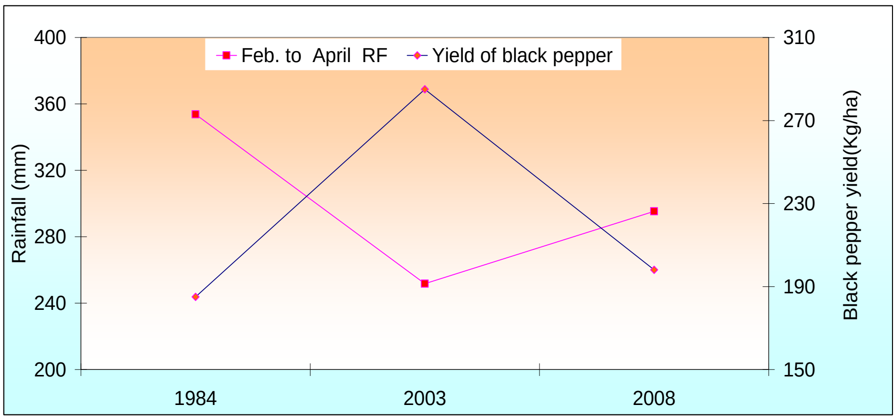


Fig.6.13. Black pepper yield at Ambalavayal during years with good summer rains

The pepper yield (productivity) was the highest during 2001 (398 Kg/ha), followed by 2000 (387 Kg/ha) and 2007(357 Kg/ha). In the above years, rainfall during March was meagre which resulted to dry weather during March. After this drought period, fairly good summer showers were received and this resulted to better yield (Table 6.7).

Table 6.7 Blossom and backing showers across Ambalavayal

year	Rainfall (mm) during March	Rainfall (mm) during April	Rainfall (mm) during March - April	Yield of dry pepper (Kg/ha)	Yield of coffee beans(kg/ ha)
1979	4.4	57.7	62.1	1011	377
1980	65.2	208.5	273.7	1480	368
1981	63.1	78.6	141.7	956	753
1982	40.0	78.6	118.6	3599	585
1983	1.5	21.5	23.0	2375	315
1984	114.5	130.0	244.5	185	811
1985	75.8	93.0	168.8	2966	514
2000	1.4	110.8	112.2	387	656
2001	12.0	206.2	218.2	398	802
2002	29.0	93.4	122.4	326	639
2003	104.2	131.4	235.6	285	739
2004	35.8	132.4	168.2	324	690
2005	54.2	147	201.2	334	660
2006	85.4	97	182.4	318	598
2007	5.2	94.8	100.0	357	705
2008	178.8	75.2	254.0	198	703

6.6 RAINFALL AND CARDAMOM

The cardamom yield showed an increasing trend from 1959-60 to 2007-08 though there was a decline in 2006-07 and 2007-08. However, the interannual variation in cardamom yield was significant due to weather aberrations. When the annual rainfall was high in 1983 (2501 mm), the cardamom yield was low (33.7 Kg/ha). It was true in 1967-68 (3036 mm), 1970-71 (2119 mm), 1977-78 (2211 mm), 1988-89 (2108mm) and 1993-94 (2226 mm) during which the yields were 34.2 Kg/ha, 22.5 Kg/ha, 27.5 Kg/ha, 31.8 Kg/ha and 59.13 Kg/ha, respectively (*see Fig.6.9*). In contrast, the cardamom yield was high when the rainfall was low. The above relationship was noticed in 1964-65 (1330.1 mm), 1975-76 (1587.5 mm), 1981-82 (1416 mm), 1985-86 (1475.1 mm), 1994-95 (1824 mm) and 1998-99 (1776.3 mm) during which the yields were high (56.1Kg/ha, 43.99 Kg/ha, 54.98 Kg/ha, 47 Kg/ha, 100.1 Kg/ha and 128.8 Kg/ha, respectively). However, it may not be true in all the cases as the yield was a complex one.

6.7 TEMPERATURE AND PLANTATIONS

The tea yield was better when the maximum temperature was below 26.5°C and minimum temperature was below 17.5°C. The upper limit of maximum temperature and minimum temperature appears to be 26.5°C and 17.5°C, respectively (Fig. 6.14).

In the case of cardamom, the upper limit of maximum temperature appears to be 26°C. No such trend was noticed in the case of minimum temperature. However, the increase in cardamom yield could be noticed with increase in minimum temperature within the boundary of 17°C and 18°C in majority of the years. Such relationship exists between the minimum temperature and coffee yield also.

Coffee yield appears to be poor when the maximum temperatures go beyond 26.9°C. Interestingly, there was a negative relationship between the mean temperature and coffee yield. In the case of black pepper, the berry yield was low when the maximum temperature goes beyond 27.4°C while it can tolerate an upper limit of minimum temperature as 18°C. The growing degree days (heat unit) versus crop yield appears to be in the same fashion as in the case of temperature since it is a function of temperature. As seen in the case of high annual rainfall, all the four plantation crops respond negatively to high maximum temperature. Being thermo-sensitive crops, any increase in temperature beyond the upper limits will adversely affect the yield. The upper limit of maximum temperature for all the crops tested vary between 26 and 27°C except in the case of black pepper which can tolerate up to 27.4°C. The boundary of minimum temperature varied between 17°C and 18°C for all the four crops tested.

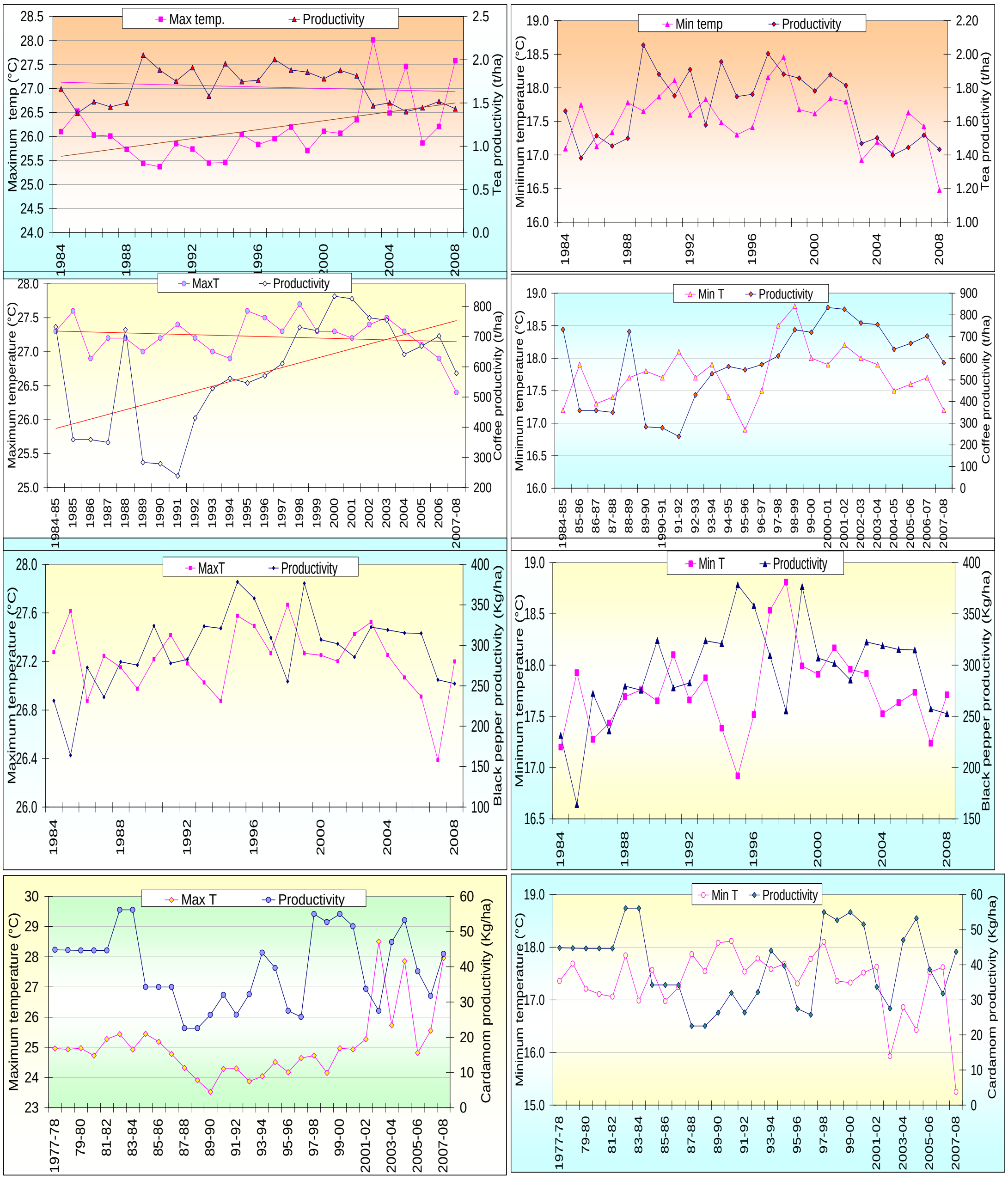


Fig. 6.14 Temperature and productivity of plantation crops

6.7.1 Temperature and tea

The maximum temperature was below 26.5°C in majority of the years during the study period. It is interesting to note that the maximum temperature in the recent years was highly variable from 2002 to 2008. The tea yield was always higher when the maximum temperature was below 26.5°C. If it was more than 26.5°C, the tea yield was low. The maximum temperature was high during 2003 (28.0°C), 2005 (27.5°C) and 2008 (27.6°C) during which the tea yield was low 1.47 t/ha, 1.39 t/ha and 1.43 t/ha, respectively. Therefore, increase in temperature beyond 26.5°C is likely to affect the tea yield adversely as noticed. The tea yield was also adversely affected since 2002 onwards due to high variability in maximum temperature. The maximum temperature and productivity trends also indicated that the maximum temperature was in increasing trend while the yield declining. It revealed that the maximum temperature had a negative correlation with productivity ($r = -0.564$) and production ($r = -0.45$). It is significant at 1% level and 5% level in the case of tea productivity and production, respectively.

It indicated that there exists an inverse relationship between the annual minimum temperature and tea yield as in the case of rainfall. When the minimum temperature was high (17.7°C) in 1985, the tea yield was low (1.38 t/ha). Similar was the case in 1987 during which the tea yield was low (1.45 t/ha), followed by 1988 (1.51 t/ha), 1991 (1.75 t/ha), 1993 (1.58 t/ha), 1998 (1.88 t/ha), 2006 (1.45 t/ha) and 2007 (1.52 t/ha). In contrast, tea yield was comparatively high when the annual minimum temperature was low. It was evident in 1980 (2.05 t/ha), 1990 (1.91 t/ha), 1992 (1.91 t/ha), 1994 (1.95 t/ha), 1995 (1.75 t/ha) and 1996 (1.76 t/ha). Such was the case in the remaining years also. It reveals that the minimum temperature and tea yield was inversely related. It was observed that the above relationship holds good in majority of years (60 per cent) during the study period. A significant negative relationship was obtained between the minimum temperature and tea productivity (r= -0.58) and production (r= -0.51). It is significant at 1% level and 5% level in the case of tea productivity and production, respectively with minimum temperature.

It was also found that the tea yield was high when the minimum temperature was below 17.5°C. The influence of temperature on yield indicated that it performed better when the maximum temperature was below 26.5°C while minimum temperature below 17.5°C. The study revealed that the optimum temperature for tea productivity appears to be 26.5°C in terms of maximum temperature while 17.5°C in the case of minimum temperature

Based on the experimental data (Kumar and Kumar, 2011) it was explained that the cumulative effect of maximum temperature, after noon relative humidity and rainfall contributed 82 per cent variation in tea yield. The contribution of sunshine hours in tea yield variation was 8.25 per cent while other variables which include minimum temperature, relative humidity in the morning and number of rainy and sunny days collectively contributed to 8.61 per cent variation.

6.7.2 Temperature and coffee

It revealed that maximum temperature and coffee yield has an inverse relationship in majority of the years. When the maximum temperature was high, the coffee yield was low. It was evident in 1985-86 (0.36 t/ha), 1990-91 (0.28 t/ha), 1991-92 (0.24 t/ha) and 1992-93 (0.43 t/ha). Similar was the case in 1986-87, 1987-88, 1989-90, 1994-95, 1995-96, 1996-97, 1997-98 and 1998-99 during which the coffee yield was low. In contrast, comparatively better yields were obtained during 2000-01(0.83 t/ha), 2001-02 (0.83 t/ha) and 2006-07 (0.71 t/ha), when the maximum temperature was comparatively low. It was also revealed that whenever maximum temperature above 26.9°C, coffee yields were low in majority of the years under the study period. On an average, majority of the years followed the inverse relationship with maximum temperature.

It was also evident that whenever the maximum temperature was above 26.9 °C, the coffee was low. In contrast, high yields were obtained only in 2000-01 (0.83 t/ha) and 2001-02 (0.83 t/ha), when the maximum temperature was 27.3°C and 27.2°C, respectively. A sharp decline in maximum temperature was evident from 2003-04 onwards. It reveals that maximum temperature above 26.9°C may adversely affect the coffee yield. Wide inter-annual variability was observed in minimum temperature. It revealed that there exists an inverse relationship between minimum temperature and productivity.

The productivity was low when the minimum temperature was high during 1989-90 (0.28 t/ha), 1990-91 (0.28 t/ha), 1991-92 (0.24 t/ha) 1992-93 (0.43 t/ha) and 1993-94 (0.53 t/ha). Similar was the case during 1997-98 (0.61 t/ha) and 1998-99 (0.73 t/ha). In contrast, when the minimum temperature was low, coffee yields were high. It was evident since 2001-02 onwards. The yield was high when the minimum temperature was high. It is interesting to note that the minimum temperature and yield followed similar trend from 2001-02 onwards

It was also observed that only four years recorded minimum temperature above 18°C, during which coffee yield was low. It indicates that minimum temperature above 18°C may adversely affect the coffee yield. Minimum temperature range between 17 and 18°C may be conducive for coffee plant as is evident from the data.

6.7.3 Temperature and black pepper

It revealed that when the annual maximum temperature was high, the yield was low. For example, the annual maximum temperature was high during 1985 (0.16 t/ha), 1987 (0.24 t/ha), 1991 (0.28 t/ha), 1998 (0.26 t/ha) and 2002 (0.29 t/ha), the yields were low. In contrast, when the mean annual maximum temperature was low, the yields were high. It was evident in 1990 (0.323 t/ha), 1993 (0.32 t/ha), 1994 (0.32 t/ha), 1995 (0.38 t/ha), 1996 (0.36 t/ha), 1999 (0.38 t/ha) and 2006 (0.31 t/ha). It revealed that mean annul maximum temperature above 27.4°C may adversely impact the black pepper yield.

As in the case of maximum temperature, when the minimum temperature was high, the black pepper yield was low. It was evident in 1985 (0.16 t/ha), 1997 (0.31 t/ha) and 1998 (0.26 t/ha). In contrast, when the mean annual minimum temperature was low, as noticed in 1990 (0.32 t/ha), 1993 (0.32 t/ha), 1994 (0.332 t/ha), 1999 (0.38 t/ha), 2005 (0.32 t/ha) and 2001 (0.31 t/ha), the yields were high (Fig. 6.14). The highest yield was obtained in 1995 when the mean annual minimum temperature was 16.9 °C (lowest).

6.7.4 Temperature and cardamom

It indicated that when the annual maximum temperature was high, the yield tends to be low and when it was low, the yield tends to be high. From 1977-78 to 1988-89, when the annual maximum temperature was high, the cardamom productivity was low. The yield recorded was comparatively high, when the mean annual maximum temperature went down. The increase in yield continued from 1989-90 to 2001-02. Interannual variability in maximum temperature was more pronounced in the recent decades. The annual maximum temperature during 2002-03 even shot up to 28.5°C during which the yield was low (0.21 t/ha), as against the mean maximum of 25.1°C. Similar was the case in 2004-05 (0.21 t/ha) and 2007-08 (0.18 t/ha) when the maximum temperature was high. In contrast, when the maximum temperature was low in the recent years in 2003-04 (0.21 t/ha), 2005-06 (0.24 t/ha) and 2006-07 (0.21 t/ha), the yields were high. It also indicates that annual maximum temperature above 26°C may adversely affect the yield of cardamom

The relationship between the annual minimum temperature and cardamom is similar to that of the relationship between maximum temperature and yield. It reveals that when the annual minimum temperature was high (between 17 and 18°C), the yield was low. It was evident from 1977-78 to 2001-02. From 2002-03 onwards, annual minimum temperature exhibited wide inter-annual variability and even went up to 15.3°C in 2007. When the minimum temperature showed fluctuations from 17°C, the yield was more or less steady but with the decline in 2006-07 and 2007-08, yield also declined accordingly. The decline in minimum temperature across the highranges may be attributed to the opening of the forest canopies due to deforestation in the recent years. It indicated that rise in minimum temperature above 18°C adversely affect cardamom yield.

6.7.5 Heat units and plantation crops

The heat unit concept was taken in to account to explain the relationship between temperature and crop yields of all the four crops tested as the heat units depend on the mean and base temperature. The base temperature was considered as 13°C in the case of plantation crops below which the crop growth ceases. The heat units were worked out based on the formula given below.

HU= Tmax+Tmin/2- Tb

Where Tmax is the maximum temperature during the day

Tmin is the minimum temperature of the day

Tb is the base temperature (13°C) below which no growth takes place.

All the four crops responded negatively with the heat units (Fig. 6.15). It indicated that whenever the heat units were more, the yields were low and vice versa as in the case of maximum and minimum temperature. Of course, the relationship may not be true always as the yield is a complex one and depends on several other environments factors. Interestingly, the yield in black pepper is low while coffee yield is high with the same amount of heat units. It indicated that the thermal environment is more suited to coffee when compared to that of black pepper. It appears that the plantations viz., cardamom, tea, coffee and black pepper may respond better to thermal regimes as they are thermo-sensitive and predominantly growing across the highranges.

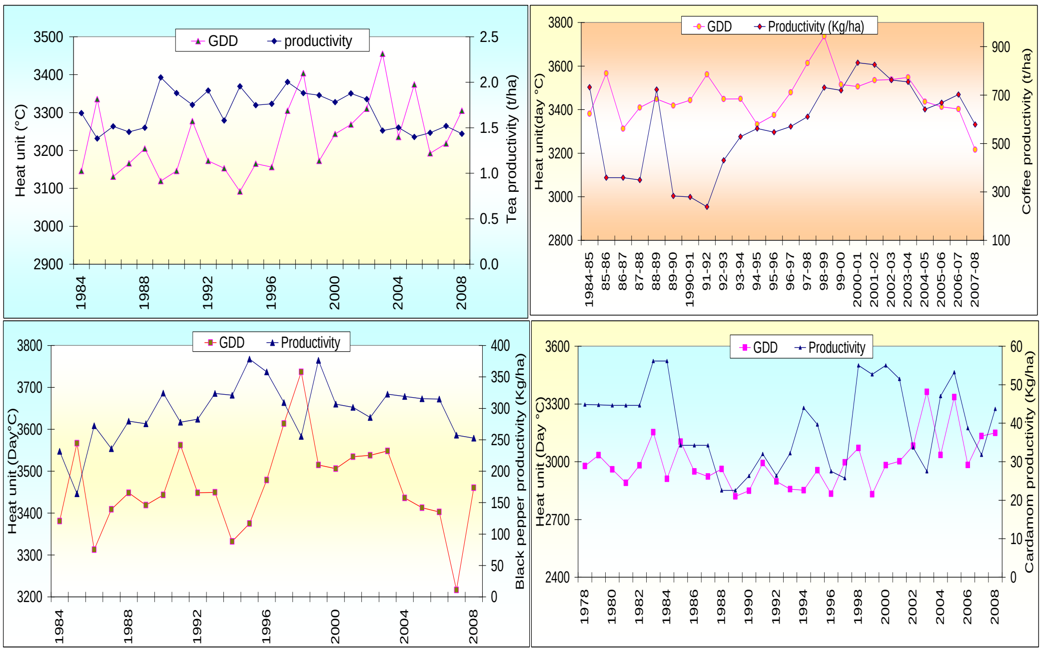


Fig. 6.15 Growing Degree Day and plantations crops

6.7.5.1 Tea

The relationship between Growing Degree Days (GDD) and yield also exhibited similar trend as in the case of annul minimum temperature. It was an inverse relationship. For example, GDD was high in 1985 (4442.3°C), 1998 (4511°C), 2003 (4562.7°C), 2004 (4333.3°C), 2005 (4481°C), 2006 (4299°C), 2007 (4325°C) and 2008 (4402°C) and the yield recorded was poor (1.38 t/ha, 1.88 t/ha, 1.48 t/ha, 1.5 t/ha, 1.39 t/ha, 1.44 t/ha, 1.51 t/ha and 1.43 t/ha, respectively). On the other hand, yield recorded was comparatively better when the GDD was low. It was evident that yields were better when the GDD was low as seen in 1989, 1990, 1992, 1994, 1996, 1997, 1999, 2000, 2001, 2002. In majority of the years, inverse relationship hold good in the case of GDD and tea yield as evident in the case of maximum and minimum temperature and it is a function of mean and base temperature (Fig. 6.15).

6.7.5.2 Coffee

As in the case of maximum and minimum temperature, Growing Degree Days (GDD) or heat unit showed an inverse relationship with coffee yield. Whenever the GDD was high, coffee yield was low and vice versa. For example, when GDD was high, low yields were obtained. It was evident during 1985-86 (0.36 t/ha), followed by 1986-87 (0.36 t/ha), 1987-88 (0.35 t/ha), 1989-90 (0.28 t/ha), 1990-91 (0.28 t/ha), 1991-92 (0.24 t/ha), 1992-93 (0.43 t/ha), 1997-98 (0.61 t/ha) and 1998-99 (0.73 t/ha) as against the normal of 0.57 t/ha. Comparatively high yields were obtained during 1984-85 (0.73 t/ha), 1988-89 (0.73 t/ha), 1994-95 (0.56 t/ha) and 1995-96 (0.55 t/ha as against the normal of 0.57 t/ha when the GDD was low. It is interesting to note that from 1999 -2000 onwards, GDD and yield followed similar pattern as noticed in the case of minimum temperature.

6.7.5.3 Black pepper

The relationship between the GDD and black pepper yields was the same as in the case of maximum and minimum temperatures. Higher yields were obtained when GDD was low and vice versa. For example, GDD was high during 1985 (3566°C) and 1999 (3737°C) and the yield was low (164 Kg/ha and 255 Kg/ha, respectively). In contrast, high yields were obtained when the growing degree days or heat units were low. For example, yield was 378 Kg/ha in 1995 while the heat unit was low (3479°C). Similarly, yields during 1986, 1987, 1988, 1989, 1990, 1991, 1992 and 1993 also showed the same trend. In majority of the years (92 per cent) the above pattern was observed.

6.7.5.4 Cardamom

The Growing Degree Days (GDD) and cardamom yield followed the similar pattern to that of maximum and minimum temperature. When the GDD was high, the yield was low and vice versa. It was evident that when the GDD was high 1984 to 2003, the yield was always low. When the GDD was high (0.028 t/ha) in 1985, 1991 (0.064 t/ha), 1998 (0.111 t/ha) and 2003 (0.21 t/ha), the yields were low. In contrast, during 2004 (0.215 t/ha), 2006 (0.240 t/ha) and 2007 (0.207 t/ha), the yields were high when the GDD was low.

6.8 IMPACT OF WATER DEFICIT DURING SUMMER

The prolonged dryspells during the summer adversely affect some of the plantation crops like cardamom. The cardamom production was very low during 1983 (172.2 Kg) when the water deficit from December to May was high

(270 mm). Such trend was seen in 1987, 1989, 1992, 1994, 1998, 2004 and 2007 during which the water deficit was 211 mm, 140 mm, 185 mm, 111 mm, 200 mm, 134 and 125 mm, respectively. It revealed that there exists a strong negative relationship between water deficit during summer and cardamom yield. Higher the water deficit during the summer months (December -May), lesser is the cardamom yield and vice versa (Fig.6.16). The yield variability was explained to an extent of 77 per cent based on soil moisture deficit during summer. Such relationship is lacking in the case of tea, coffee and black pepper.

Of course, the effect of soil moisture status during summer could be felt to some extent in the case of tea while not in the case of black pepper and coffee. Interestingly, black pepper responded positively to water deficit indicating that the black pepper yield is relatively better when the crop is exposed to more soil moisture stress. In the case of black pepper there should not be any dryspell once rain commences till spike elongation and berry formation. Normally, flushing in black pepper commences with the onset of monsoon. In some years, when the pre-monsoon showers are optimum, flushing commences in the case of black pepper. Thereafter, any dryspell adversely affect the flowering behaviour of black pepper. That is why it is believed that black pepper needs a sort of prolonged dryspell before flushing commences. In the case of coffee, it only needs timely blossom and backing showers in February/March and March/April as noticed. Coffee thrives well and produces better under optimum and timely blossom and backing showers. That is the reason, why, the effect of water stress on coffee is not felt much unlike in the case of cardamom.

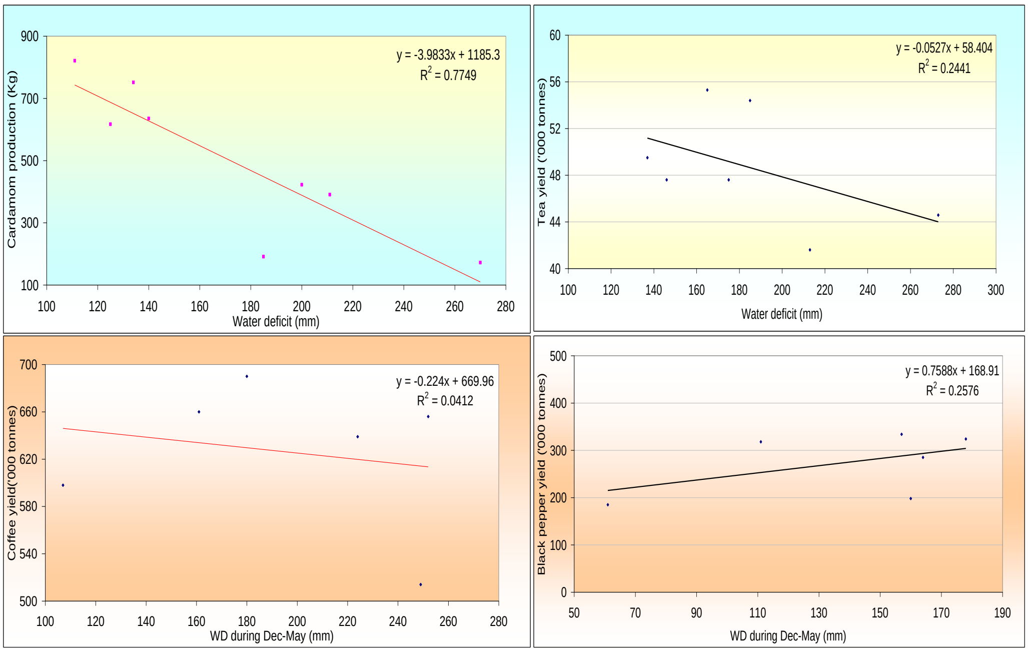


Fig.6.16 Water deficit versus yield relationship in plantations

The study on the effect of water deficit during summer on the four selected plantation crops across the highranges revealed that the water deficit during summer months adversely affect cardamom to a large extent (R^2 =0.77) while not in the case of tea, coffee and black pepper. Interestingly, black pepper respond positively to water deficit during summer to some extent as the reason explained above.

6.9 WEATHER ABNORMALITIES AND YIELDS

The effect of climate change on plantation crops' production is not as evident as in the case of climate variability or rather, it may be having an indirect effect by way of climate variability, such as the occurrence of floods and droughts. The inter-annual variability in yield of plantation crops are affected by weather aberrations occurring from time to time such as abrupt changes in weather by way of increasing summer droughts due to no or scarce rainfall, high summer temperature, unusual summer showers and heavy and prolonged monsoon rains due to monsoon uncertainties. Since the economy of the State is to a greater extent determined by the plantation sector, decline in plantation crops' production is a concern. In the event of global warming and climate change, the occurrence of weather abnormalities and extreme weather events are likely to occur and reoccur. Such events will deleteriously affect the plantation crops production in the State. Hence, it will be of immense use under the projected climate change scenario, if the impacts of abnormal weather events on plantation crops' productions are quantified based on the past data. Hence, an attempt was made to understand the effects of extreme weather events on the yield of the four selected plantation crops.

Case study

6.10 RISE IN MAXIMUM TEMPERATURE DURING JANUARY-MARCH, 2004 IN WAYANAD AND ITS IMPACT ON BLACK PEPPER

2004 was identified as one of the four disastrous drought years in Kerala. The State has witnessed severe water shortages, extreme temperatures and drying up of surface wells and ponds during that year. Drinking water problem was severe. Most of the plantation crops were affected due to the severe water stress and extremely high surface air temperatures. The black pepper yields' were not seen affected much due to summer drought in 2004. It is true that productive pepper plants can withstand continuous dryspells and produce better harvest if moderate summer showers during April-May are received before flowering process initiates in June after the onset of monsoon rains. But, black pepper vines, especially young and senile ones and vines planted in open spaces may not be able to tolerate extreme high temperatures as experienced in summer

2004. Black pepper vines planted in shade may be able tolerate such extreme temperatures to a certain extent. It was reported that pepper vines in some of the pepper plantations of Wayanad District were wiped out due to the extreme high day temperatures experienced throughout the dry period from January to March in the absence of soil moisture. Hence, an investigation was made to examine the march of day temperatures from January to March 2004.

It revealed that 2/3rd of the total days experienced above normal temperatures (Fig.6.17). Increase in day maximum temperature was noticed from the beginning of January to 21st March, 2004. The day maximum temperature shot above normal and reached as high as 34.7°C on 20th March, 2004 registering an increase of 3.6°C above normal followed by 34.6°C on 19th March, 2004, registering an increase of 3.0°C. On an average, the increase in maximum temperature over normal was 0.6°C.

The decline in rainfall continuously from 1999 to 2003 led to hydrological drought in monsoon 2004 and several irrigation channels dried up. In the absence of soil moisture, increase in maximum temperature affected the black pepper gardens and young pepper vines dried up to a considerable extent. Though the young pepper vines dried up, the yield decline in black pepper is insignificant due to drought in summer. Such was the situation in summer 1983 too during which severe drought conditions were noticed and at the same time, black pepper yielded better.

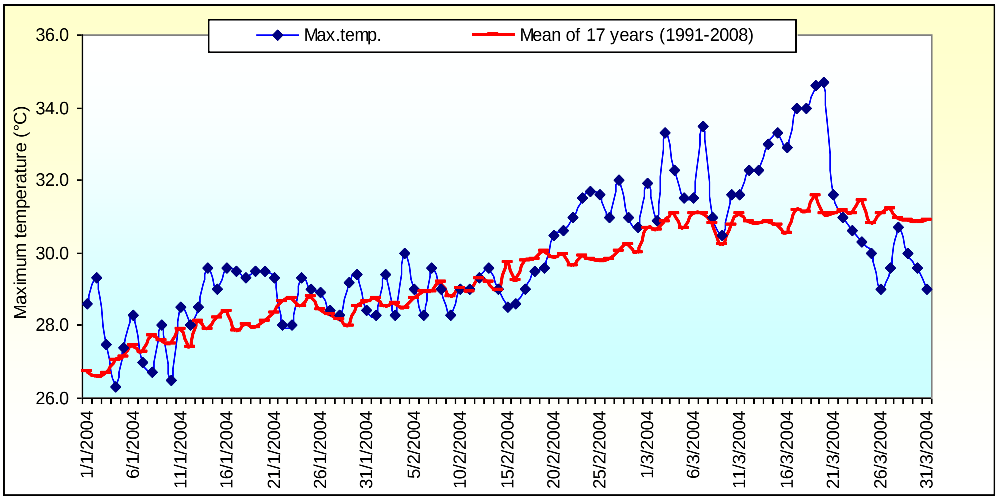


Fig.6.17 Maximum surface air temperature from January- March, 2004 in Wayanad district

It revealed that rise in maximum temperature in the absence of soil moisture during summer may not adversely affect the black pepper performance as the berry yield was not affected much though mortality was noticed in the case of young black pepper vines and the ones under the open conditions. In contrast, the yield decline in other three crops like cardamom, tea and coffee was evident due to summer drought.

6.11 IMPACTS OF CLIMATE VARIABILITY AND CLIMATE CHANGE

There was a decline in annual rainfall during the study period while increase in surface air temperature. The annual rainfall was significantly low in the decade 1981-90 and led to several summer droughts. As a result, increase in temperature was noticed in the above decade. The rate of increase in temperature was more evident since 1980s. Decline in rainfall and increase in temperature led to decline in moisture index and increase in aridity index, which is an indicator for dryspell. It led to more number of droughts (nine) in the present tri-decade of 1981-2009 when compared to that of 1951-80. The tri-decadal analysis also indicated that the decline in rainfall and moisture index, increase in temperature and aridity index were evident in the tri-decade of 1981-2009 (Figs.6.18 & 6.19). All these factors reveal that the global warming and climate change are real in Kerala. Therefore, warming and dryness within the humid climate in the State of Kerala is a concern in the plantation sector of the State.

The area under cardamom was in increasing trend from 1952 to 1990 and thereafter there was a decline in the recent decades. In the case of tea, the area decline was evident since 1950s and it was the lowest in the decade 1981-90. A marginal increase was noticed thereafter in the area under tea. However, the increase in area was evident in the case of coffee and black pepper during the study period while decline in area under tea and cardamom. Interestingly, the production of all the plantation crops was in tune with the area, it was so in the case of cardamom and tea. A steady increase was noticed in plantation crop production except in the case of black pepper during 1971-80.

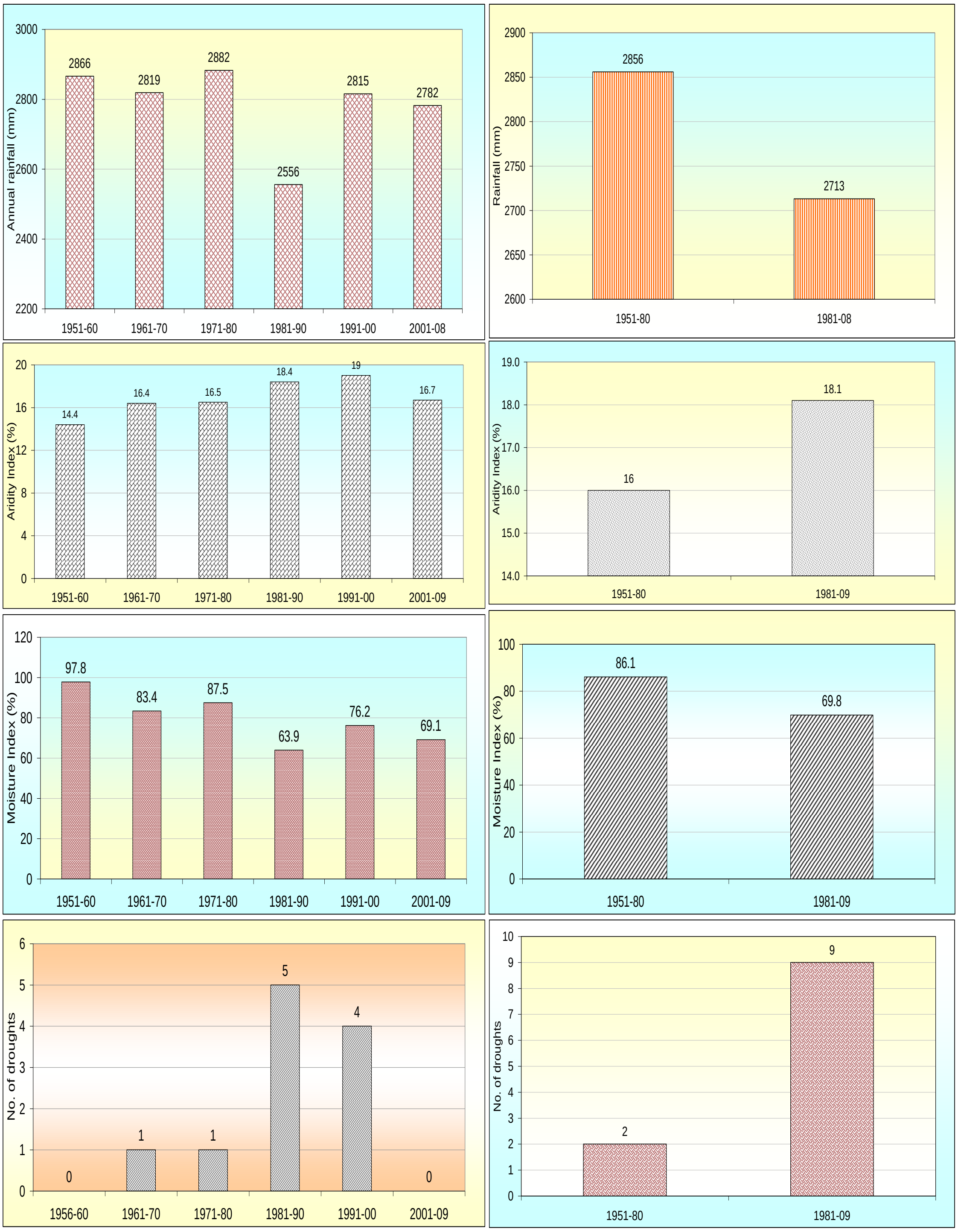


Fig.6.18 Decadal and tri-decadal changes in annual rainfall, aridity index, moisture index and droughts over Kerala

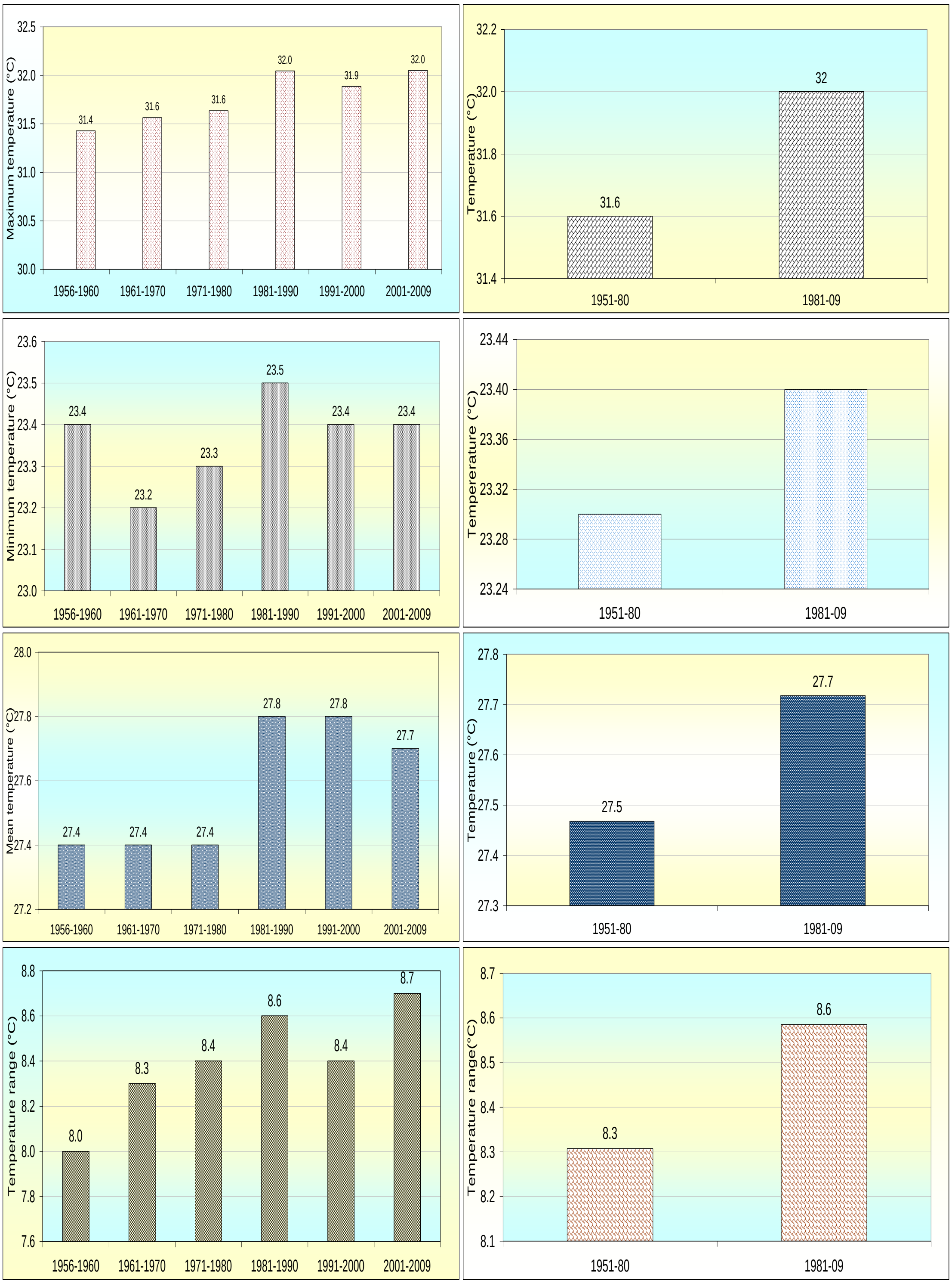


Fig.6.19 Decadal and tri-decadal changes in temperature across the State of Kerala

There was a sharp increase in capsule productivity in the case of cardamom and coffee beans in the recent decade of 2001-2008 while not so in the case of tea and black pepper. There was a sharp decline in productivity in the recent decades in the case of black pepper and tea. Overall, all the four plantation crops showed increase in productivity in the present tri-decade of 1981-09 when compared to that of 1951-80. Despite increase in temperature, decline in rainfall, increase aridity index and decline in moisture index, increase in plantation crop productivity was evident in the tri-decade of 1981-2009.

It reveals that the plantation crops' productivity is vulnerable to climate variability rather than climate change. However, the crop simulation models in the case of tea and coffee indicated that the area is likely to decline if the temperature increase is by 2°C and some of the current areas under tea and coffee may disappear in the above situation of increase in temperature (IPCC, 2007). In fact, such trend was not noticed since last thirty years though the rate of increase in maximum temperature was 1.46°C during the present tri-decade. Instead of decrease in area, production and productivity due to increase in temperature, there was an increasing trend on long term basis.

The study revealed that there was a shift in area among these four selected crops. At the cost of tea and cardamom area, the area under coffee and black pepper was increasing and it was phenomenal since last two decades. There may be several reasons for shift in area among the four plantation crops. From farmers' point of view, a crop mix with combination of coffee and black pepper may be beneficial under the current climate variability scenario as one crop like coffee suffers, another crop like black pepper gains in a same weather situation. It may not be so in the case of monocrop like tea and cardamom. It may be probably, one of the reasons why, shift was noticed in the cropped area of these four plantations. However, it needs further probe in depth from all the angles in view of the climate change scenario.

The reason in high cardamom productivity could be due to the introduction of high yielding drought/pest resistant varieties by the faming community across the cardamom tract. Vagaries in monsoon, distribution of rainfall pattern, frequent occurrence of droughts, and increase in maximum and minimum temperatures, deforestation and shifting land use pattern have altered the natural habitat of cardamom to a greater extent. In the projected climate scenario, Cardamom Hill Reserves of Idukki district may pose a threat from decline in monsoon rainfall and rapid changes in thermal regimes. Such events are likely to accelerate the shift in cropping system across the highhranges as noticed at present.

In the case of tea, area was the least during 1981-90. It was the warmest and driest decade over Kerala. Replacing of the senile and unproductive plantations with young ones, conversion of unproductive and uneconomical plantation area for non-agricultural purposes were some of the major reasons for decline in area under cultivation across the State. It is true that 1981-90 was the warmest and driest decade as far as Kerala is concerned. Tea production was adversely affected during 1983, 1985 and 1987 as evident from the data.

1987 was the warmest year on record, followed by 1983. Also, 1983 was the warmest summer across Kerala. 1982-83 was an unprecedented summer drought year that adversely affected most of the plantation crops of the State. Tea production was also affected during that year. The tea leaf production was 44600 tonnes during 1982-83 while it was 58200 tonnes in 1983-84 when there was no summer drought. Similarly tea yield was poor in 1987 (5034660 tonnes), when compared to preceeding and proceeding years. In terms of productivity also, the productivity was poor during the drought year 1982-83 (1266 Kg/ha). It showed a decline of 3.98 per cent when compared to the preceeding year 1981-82 (1318 Kg/ha). During the warmest year of 1987 also, the tea productivity was less (1453 Kg/ha). It was less by 4.03 per cent when compared to the previous year 1985-86 (1514 Kg/ha). It indicates that tea is more vulnerable to abrupt changes in weather during the peak crop growth period. It was one of the reasons for decline in the yield since last one decade. Change in cropping pattern, variations in leaf quality and increased pest attacks triggered by transformed climatic conditions have put the tea industry in Kerala under tremendous pressure.

Pest attacks, especially in the Vandiperiyar-Peermedu belt in Kerala, had resulted in doubling of expenses on pest control and fighting diseases over the past five years. It appears that there was also a noticeable increase in atmospheric temperature in the recent years. Increased temperature has resulted in the outbreaks of various diseases and pest attacks, especially in the belt where these have traditionally been a problem. Tea leaves needed a lot of sunshine. Slow growth induced by poor sunshine resulted in leaves becoming hard and leathery, which may result in poor quality. The tea leaf production had been significantly hit by heavy rain during the September-December phase in 2010, which used to be the high cropping period. Reports indicate that there have also been significant swings in relative humidity, rainfall and sunshine hours per day when the decennial mean is compared with conditions in 2009. It was observed that climate variability appeared to favour the building of sucking pests like red spider mite. Hence, the weather aberrations not only adversely affect tea productivity directly but also indirectly through pest and disease intensity.

Temperature (both maximum and minimum) had a cumulative impact on crop productivity irrespective of the topography. Each weather variable either alone or in combination imposed stress on the plants and the compounded effect of climate variability not only affected the plant metabolism but also influenced the crop productivity. Therefore, a gradual change in climate would not impose any deleterious impact on the crop productivity, but a sudden change may put the plants under stress and trigger a sudden outbreak of pest and pathogens. That is the reason, why, the tea productivity was less in recent years. Similar was the situation in the case of black pepper. In the case of black pepper, inter-annual yield fluctuations were more in recent years. It may be noted that though the area and production were the highest during 2001-08, the productivity declined due to weather aberrations. As indicated, if coffee performs better in a particular favourable weather, the performance of the black pepper is likely to be inferior. Hence, the crop mix of coffee with black pepper may be a better choice as practiced.

The annual productivity of coffee for about 25 years (1952-1977) was steady while inter-annual variability was high since 1979-80 to 1991-92. The decade 1981-90 was the warmest and driest. The disastrous summer drought of 1983, the warmest year 1987 and warm summers coincided with the above decade. This might be the reason for the fluctuations in yield during the decade 1981-90 when compared to 1971-80. With the more or less same area (82’000 ha) in 1981-90 and 2001-08, the crop productivity increased in 2001-08 when compared to 1991-2000. This could be due to the adoption of new varieties and agro-techniques during the recent decade. Of course, fluctuations in weather do affect the crop production to a large extent depending upon the blossom and backing showers. As indicated in the preceeding paragraph, the coffee yields increased in recent years while black pepper declined. Hence, it is clear that the plantation crops’ productivity is vulnerable to climate variability like in the case of seasonal crops rather than climate change as of now.

Chapter 7

Climate variability and cocoa production in Kerala

7.1 TRENDS IN AREA, PRODUCTION AND PRODUCTIVITY OF COCOA IN KERALA

The State of Kerala is one of the cocoa plantation states and ranked first in India. In 1980s the area under cocoa was very high and revolved around 18,000 ha. Thereafter, a sharp decline was noticed and reached to its low (6900 ha) in 1994-95. The percentage decline in area was 62 per cent. A gradual regain in cocoa area was noticed since 1995-96 onwards and stabilized at 10,700 ha in 2008-09 (Fig. 7.1).

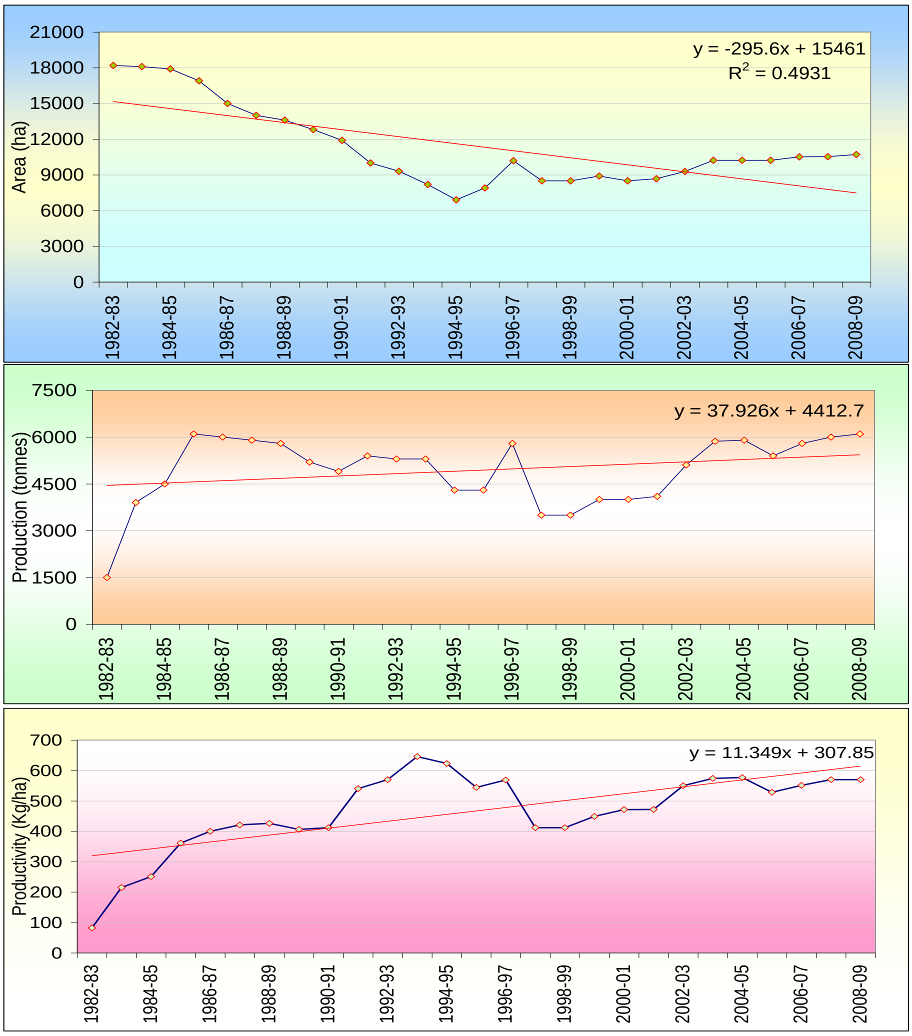


Fig.7.1 Trend in area, production and productivity of cocoa in Kerala

Overall there was sharp decline (41.2%) in area during the study period. The production and productivity was the lowest in 1982-83 (82 Kg/ha), followed by1983-84 (215 Kg/ha). In contrast, the maximum cocoa production (6000 tonnes) was recorded over Kerala in 2007-08 with lesser area. It could be attributed to increase in cocoa productivity during the above period (570 Kg/ha). The trend was similar in the case of productivity, recording the maximum (570 Kg/ha) in recent years. As a whole, the study revealed that there was a sharp decline in cocoa area while increase in production and productivity (Fig. 7.2)

7.1.1 Trends in decadal area, production and productivity

The decadal area under cocoa was also in declining trend as seen in the case of annual area. The highest area (14840 ha) was in the decade 1981-90 while the lowest (8559 ha) in 1991-00. In the recent decade, the area under cocoa has shown an increasing trend due to better price offered to cocoa farmers.

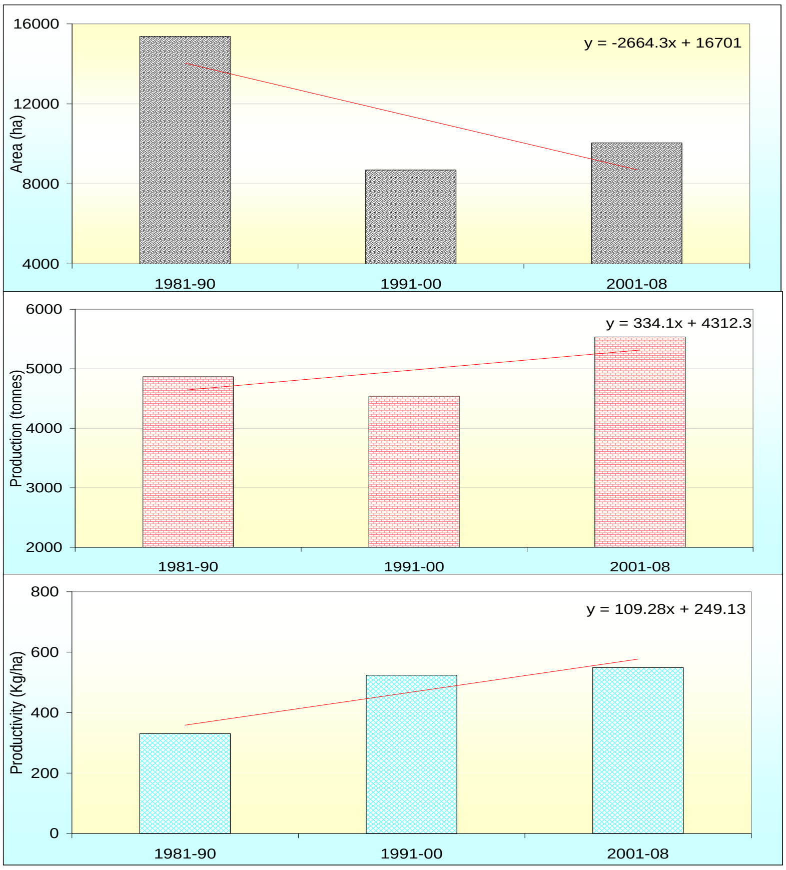


Fig.7.2 Decadal trend in area, production and productivity over Kerala

It indicates that cocoa is being cultivated by farmers during the recent years. While the area under cocoa showed a decline, production was in increasing trend. Production has been steadily increasing over the decades. The highest production (5600 tonnes) was in the recent decade of 2001-08, followed by 5170 tonnes during 1991-00. Like the cocoa production, the cocoa productivity was also increasing. The highest productivity (549 Kg/ha) was observed in the recent decade 2001-08, while the lowest (330 Kg/ha) was in the decade 1981-90.

7.2 RAINFALL REGIMES OVER KERALA

Kerala has the fortune of having the two monsoons viz., southwest and northeast and hence the rainfall pattern of the State is bi-model having two peaks one during southwest monsoon (June to September) and another during Northeast monsoon period from October to November **(**Fig.7.3). However, the bi-modal distribution of rainfall is not seen in the north Kerala as northeast monsoon is not prominent there. The major contribution (68%) of rainfall is from the southwest monsoon and northeast monsoon constitutes only 17 per cent of the total rainfall. In addition to the above, pre-monsoon showers are also a source of rainfall during the summer months. June is the rainiest month in the central and southern districts of the State, while the rainiest month is July in the northern Kerala. In general, rainfall increases from south to north of the State. While southern most part receives 1100 mm of rainfall, amount of rainfall received in northern region of the Kerala is 3600 mm. There exists wide variability in the receipt of rainfall across the State, varied from less than 1000 mm to more than 5000 mm.

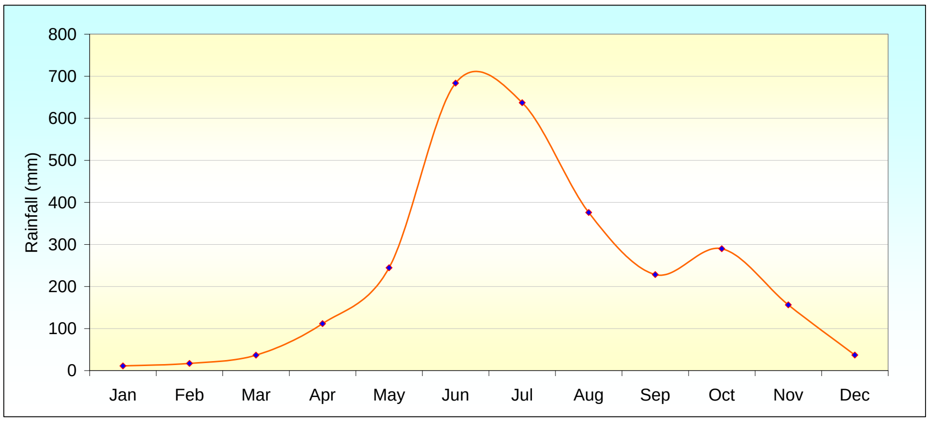


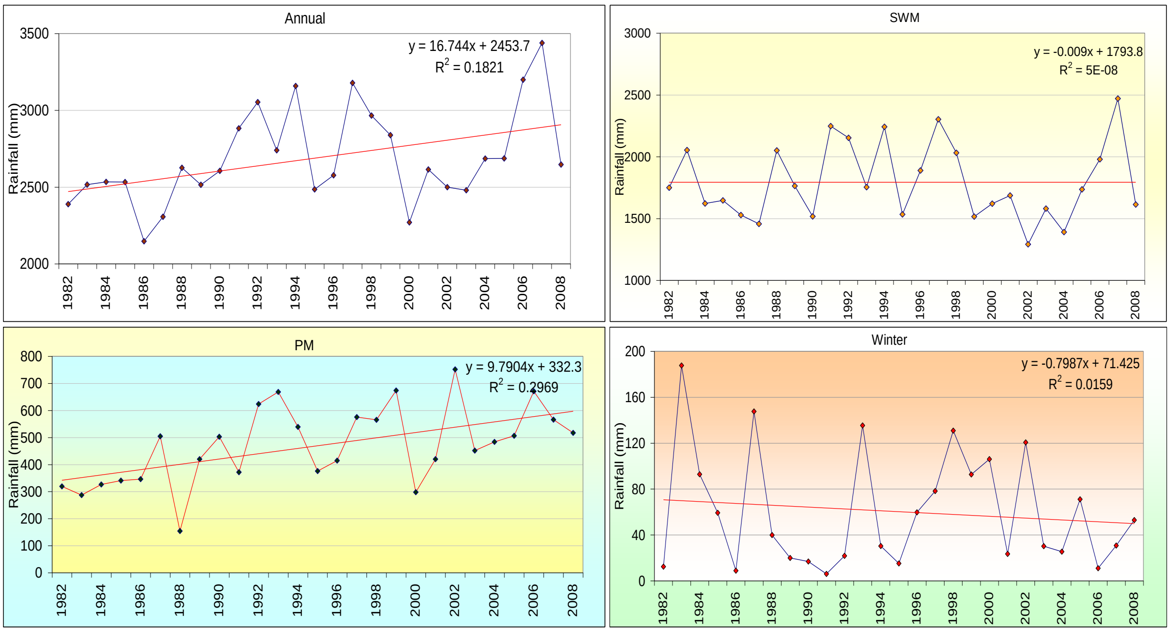
Fig. 7.3 Monthly variation of rainfall over Kerala

7.2.1 Rainfall trends

Analysis of long term rainfall data of the State showed that the annual rainfall has been exhibiting a cyclic trend/pattern to increase and decrease in a span of 40-60 years. Southwest monsoon rainfall (June to September) over the State has declined by 161 mm during the 138 year period (1871 to 2008). At the same time post monsoon rainfall (October to November) has increased by 100.6 mm. This trend may be disrupted when the data period considered for analysis is short. During the crop weather study period of 1982 to 2008, the annual rainfall of the State has shown clear tendency to increase. There has been an increase of 16.7 mm per year in annual rainfall over Kerala during this period. The increasing trend in annual rainfall during this period could be attributed to the occurrence of heavy rainfall years during the period from 1982 to 2008.

A year was considered as heavy rainfall year during which the annual rainfall was more than 3000 mm, being the sum of the average rainfall during the period plus one standard deviation. Hence, 1992 (3053.8 mm), 1994 (3159 mm), 1997 (3179 mm), 2006 (3099 mm) and 2007 (3439 mm) could be considered as heavy rainfall years during the study period. Rainfall during the southwest monsoon has shown a tendency to decline (0.009 mm per year) while increase in the post monsoon rainfall (9.8 mm per year) and summer rainfall (7.5 mm per year) . A decline in winter rainfall (0.739 mm per year) was noticed (Fig. 7.4). The seasonal trends in rainfall during the crop data period were similar to that of the long period trends (1871-2008).

As the annual rainfall is dependant on monsoon rainfall, the decline in monsoon rainfall over Kerala is the concern. About 68-72 per cent of the annual rainfall is received during the monsoon (June-September) depending upon the location. Hence, the decline in monsoon rainfall is likely to affect several sectors like generation of hydro-power, irrigation during the rabi season and drinking water during summer. Nevertheless, increase in summer and post monsoon rainfall is likely to influence favourably most of the plantation crops. Being a plantation state, it is a positive sign for sustenance of plantation crops, in terms of soil moisture availability under the projected climate change scenario.



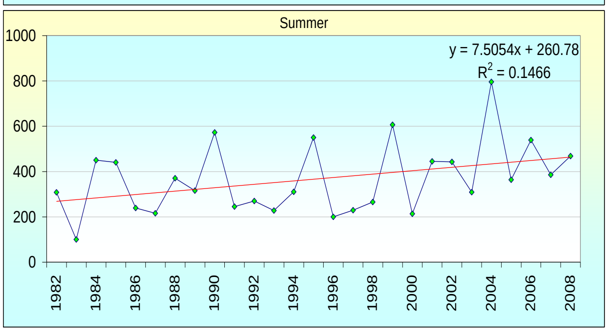


Fig. 7.4 Rainfall trends over Kerala during the study period

7.3 THERMAL REGIMES

The mean annual maximum temperature over the State is 31.8°C, varying between the lowest in July (29.2°C) and the highest (34.5°C) in March. The maximum temperature starts increasing after the cessation of post monsoon rainfall in October and reaches its peak in March - April and decline by the receipt of summer showers. The dip in maximum temperature during the monsoon season over Kerala is typical due to heavy monsoon rains. The mean annual minimum temperature over the State is 23.4°C, varying between 21.7°C in January to 25.1°C in April (Fig. 7.5). Of course, the crop is seen only in midlands and highranges as a homestead crop. Across the midlands or cocoa growing tract, the maximum temperature and minimum temperature vary between 31.8 °C and 23.4°C, respectively. However, under homestead conditions the crops are exposed to lower temperature when compared to crops grown under open.

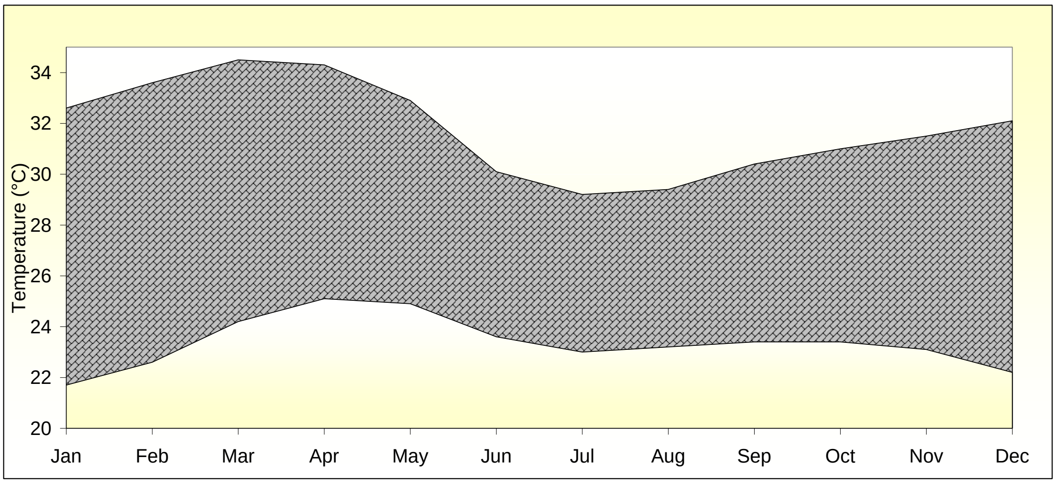


Fig. 7.5 Thermal regime of cocoa over Kerala

7.3.1 Temperature trends during the study period

During the study period, the maximum and minimum temperature over Kerala has shown a declining trend. The decline in maximum temperature was at the rate of 0.0056°C per year while it was 0.0058°C per year in the case of minimum temperature. The mean temperature and temperature range was also deceasing at the rate of 0.0042°C per year and 0.0026°C per year, respectively (Fig. 7.6).

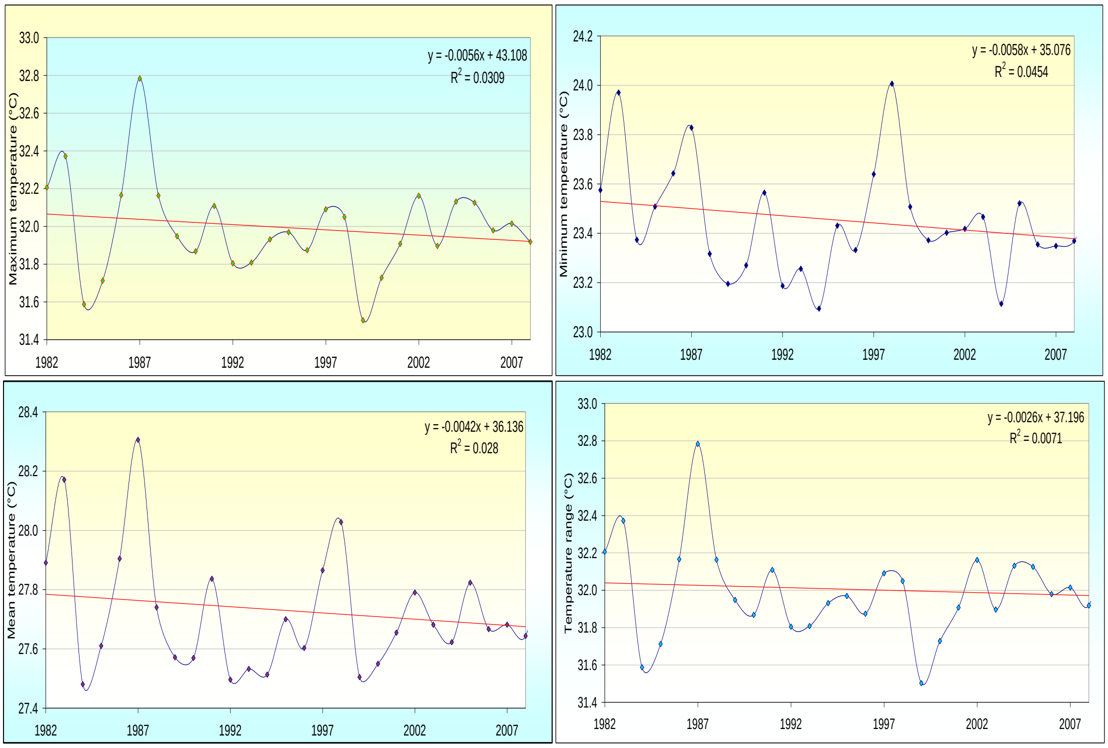


Fig. 7.6 Trend in temperature in Kerala during the study period

At the same time, long period trend in temperature of Kerala reveals that the mean annual maximum and minimum temperatures over Kerala is in increasing trend. Over a period of 54 years (1956 to 2009), the increase in maximum temperature was 0.72°C while it was 0.22°C in the case of minimum temperature. In the case of mean temperature, the increase was 0.47°C. The temperature range has shown an increase of 0.51°C. The decadal maximum temperature over Kerala was in increasing trend.

7.4 RAINFALL AND COCOA YIELD

It is a complex phenomenon to workout relationship between rainfall and the cocoa production at the State level as the crop had undergone a market crisis in 1980s and 1990s and cocoa plantations were cut and replaced with other profitable crops like rubber. It was a neglected crop for long because of the low price in the market. Recently only, farmers started to take care of cocoa plantations on commercial angle. However, high rainfall appeared to be adversely affected the annual cocoa productivity of the State. For example, the annual rainfall recorded during 1994-95 was high (3159 mm) in which annual cocoa production was low (4300 tonnes). It was also true in the case of 1997-98 (3179 mm), 1998-99 (2966 mm) and 1999-2000 (2838 mm) as the cocoa production during the above the years was recorded as 3500, 3500 and 4000 tonnes, respectively **(**Fig 7.7). In contrast, the annual cocoa production was more (6100 tonnes) when the rainfall recorded was low (2532 mm) during 1985-86. Similar trend was also noticed during 1986-87 (2147 mm), 2003-04 (2480 mm) and 2004-05 (2685 mm) and cocoa production recorded was 6000, 5870 and 5900 tonnes, respectively. High rainfall, heavy cloudiness, low bright sunshine and high relative humidity appeared to be detrimental to cocoa.

In the case of productivity also, similar was the trend noticed. Rainfall was high in 1997-98 (3179 mm) and the yield was low (412 Kg/ha). Similar was the case in 1998-99 (2966 mm) during which the cocoa yield was low (412 Kg/ha). In contrast, during low rainfall years, such as 1986-87 (2147 mm), 1993-94 (2740 mm), 1995-96 (2485 mm) and 2000-01 (2270 mm), the yield recorded was high (400 Kg/ha, 646 Kg/ha, 544 Kg/ha and 471 Kg/ha, respectively). Similar relationships were observed in the case of summer rainfall and yield also. In the case of Vellanikkara also, whenever the annual rainfall was very high, the annual cocoa yield was low. For example, the annual rainfall recorded was high (3579 mm) in 1994 against the normal

(2803 mm) and the yield during the year was low (46.8 pods/year) as evident from Fig. 7.7.

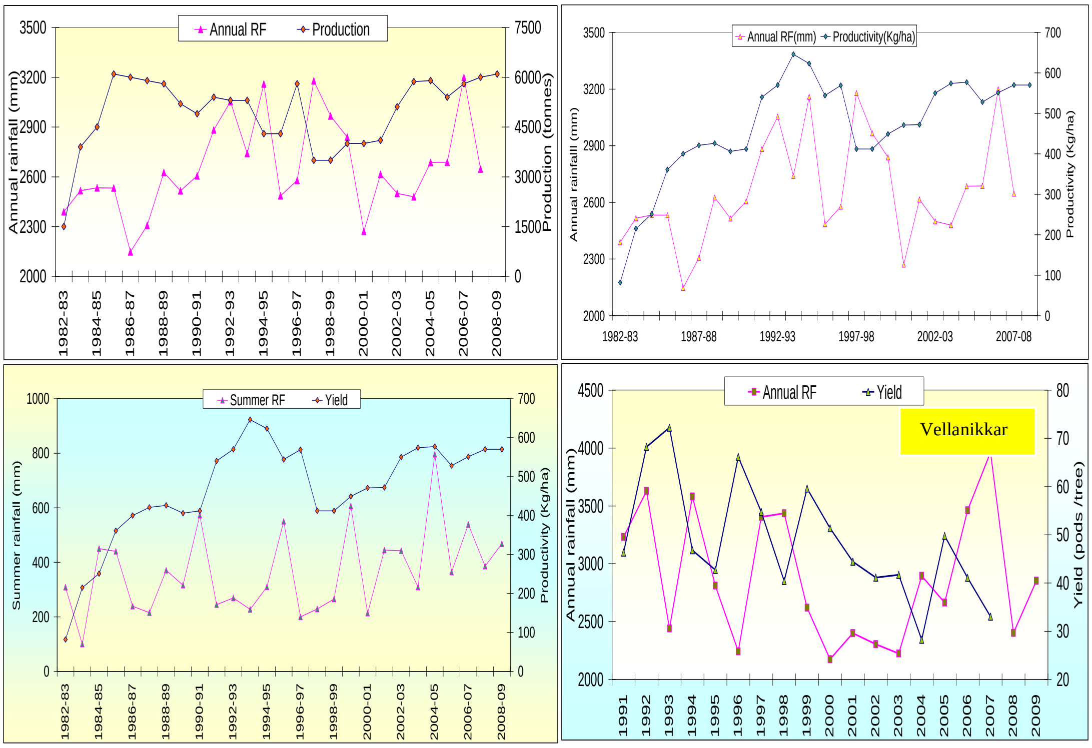


Fig. 7.7 Rainfall and cocoa yield over Kerala and at Vellanikkara

Similar trend was also noticed during 1998 (40.4 pods/tree), 2004 (28.2 pods/tree) and 2006 (41.1 pods/tree) during which the annual rainfall was 3435 mm, 2895 mm and 3460 mm, respectively. Whereas in 1993, 1996, 1999, and 2000, the annual rainfall recorded was relatively less (2439 mm, 2241 mm, 2619 mm and 2173 mm respectively) as against the normal and the annual cocoa yield during the above years was high (72.2 pods/tree, 66.1 pods/tree, 59.6 pods/tree, and 51.4 pods/tree, respectively). It revealed that the annual cocoa yield was relatively low when the annual rainfall was high against the normal rainfall and *vice-versa*.

7.5 SOIL MOISTURE AND YIELD AT VELLANIKKARA

The relationship between mean annual soil moisture and yield also indicated similar trend as in the case of rainfall. For example, the mean annual soil moisture recorded during 2003 was high (16.5%) and the yield during the year was low (41.7 pods/tree). It was also true during 2001, 2004 and 2006 (Fig.7.8) as the annual cocoa yield was low and recorded as 44.4 pods/tree, 28.2 pods/tree and 41.1 pods/tree, respectively. In contrast, the yield recorded during 1999 (66.1 pods/tree) and 2005 (49.8 pods/tree) was high during which annual soil moisture was low and recoded as 11.4 % and 11.1 %, respectively. The same trend between the soil moisture and yield was reflected as in the case of rainfall. As the soil moisture is dependant on rainfall such relationship is expected. High rainfall lead to heavy soil moisture which may result in waterlogging or sometimes flood the fields where

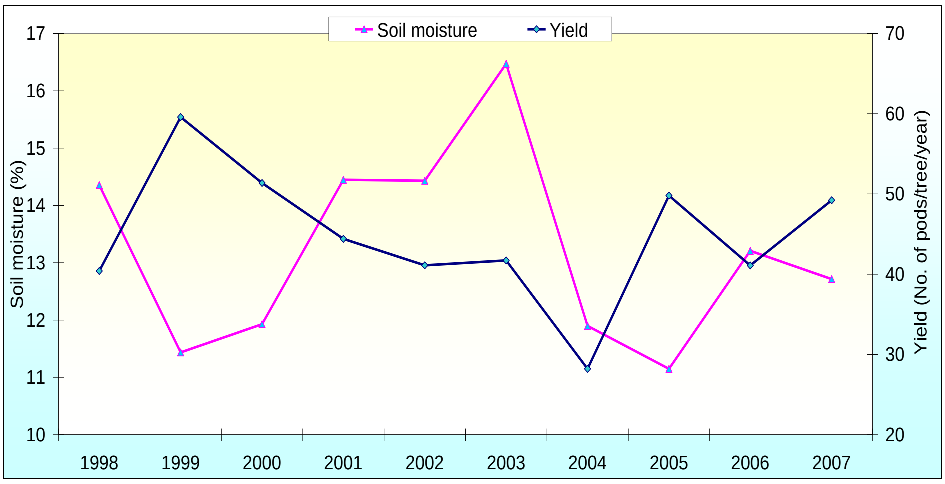


Fig.7.8 Soil moisture at 30 cm depth and cocoa yield at Vellanikkara from 1998 to 2007

cocoa is grown. It is detrimental to cocoa crop. As the yield pattern shows peak during summer, it had a negative relationship with soil moisture since it is minimal in the absence of rain during summer. In fact, any improvement in soil moisture during summer may result in good health of plant, in turn lead to better yield.

7. 6 YIELD VARIATION IN GOOD AND BAD YEARS IN DIFFERENT CLONES OF COCOA

In order to understand the monthly and seasonal yield variability in cocoa, the monthly yield data of one good yielding year (1992) and one poor yielding year (2004) was examined. It was found that the difference in cocoa yield of good year during rainy months (June to September) was very significant (344.4 per cent over the poor year) followed by summer (222 per cent) and post monsoon season (28 per cent). There was a decline of 14 per cent in winter over the poor yielding year (Fig.7.9).

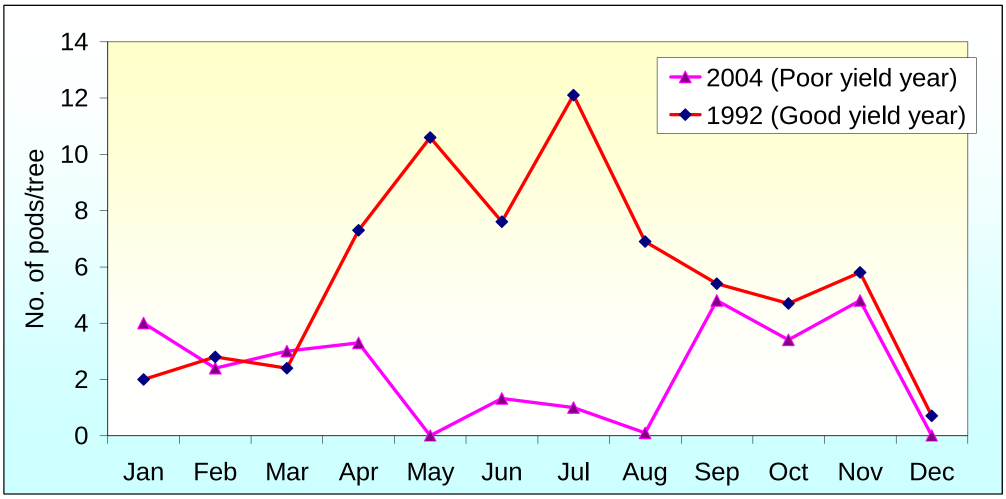


Fig. 7.9 Yield performance of cocoa during good and bad years

7.7 ANNUAL TEMPERATURE AND COCOA YIELD IN KERALA

The relationship with annual maximum temperature and yield (productivity) revealed that whenever the annual maximum temperature increases, cocoa yield decline and vice versa. For example, when the mean annual maximum temperature was high (32.8°C) in 1988, cocoa yield was low (421 Kg/ha). Similar was the case in 1982 (32.2°C) and 1983 (32.4°C) during which the cocoa yield was low (82 Kg/ha and 215 Kg/ha), respectively (Fig.7.10). In contrast, when the mean annual maximum temperature was low (31.5°C) in 1999, the yield obtained was high (449 Kg/ha). Similar relationships were found in 1985 (31.7°C), 1990 (31.9°C), 1992 (31.8°C), 1993 (31.8°C), 1994 (31.9°C), 1995 (32.0°C), 1996 (31.9°C) and 2003 (31.9°C) during which the yields were 31.6 Kg/ha, 412 Kg/ha, 570 Kg/ha, 646 Kg/ha, 623 Kg/ha, 544 Kg/ha, 569 Kg/ha and 574 Kg/ha, respectively. Cocoa yield during 1993 was high (646 Kg/ha) when the annual maximum temperature was low (31.8°C). Similar situations prevailed during 1995 (623 Kg/ha), 2003 (574 Kg/ha), 2004 (577 Kg/ha) and 2007 (570 kg/ha) during which the maximum temperatures were 31.9°C, 31.9°C, 32.1°C and 32.3°C, respectively. Such situations were seen in majority of the years (89 per cent). The study indicated that the mean annual maximum temperature has a negative impact on the yield of cocoa. It also revealed that when the mean annual maximum temperature is above 32.2°C, cocoa yield was adversely affected.

7.7.1 Summer maximum temperature and yield

Similar trend was observed when the relationship between the summer (January-March) maximum temperature and cocoa yield was examined. When the summer maximum temperature was high (35.1°C) in 1983 cocoa yield was low (215 Kg/ha). Similar events were noticed in 1987 and 2008 during which the summer maximum temperature was high (35.2°C and 34.8°C, respectively), cocoa yields were 421 Kg/ha and 412 Kg/ha, respectively (Fig.7.10). In this case, when the summer maximum temperature was above 34.7°C, yield decline was seen. In contrast, when the summer maximum temperature was low (32.9°C), cocoa yield was high (449 Kg/ha). Similar relationships were observed in 1990, 1993, 1994, 2004 and 2008 during which the maximum temperatures were 33.7°C, 34.3°C, 33.9°C, 33.6°C and 33.3°C, respectively and the yields were high (412 Kg/ha, 646 Kg/ha, 623 Kg/ha, 577 Kg/ha and 570 Kg/ha, respectively.)

As observed in the case of annual maximum and summer maximum temperature, annual mean temperature also showed a similar trend with yield. It revealed that when the annual mean temperature was high (28.3°C), cocoa yield was low (421 Kg/ha). Similarly, in 1982 (27.9°C), 1983 (28.2°C), 1986 (27.9°C) and 1998 (28.0°C) during which the annual mean temperature was high, cocoa yields were low (82 Kg/ha, 215 Kg/ha, 400 Kg/ha, 421 Kg/ha and 412 Kg/ha, respectively). In contrast, when the annual mean temperature was low (27.5°C), in 1992, cocoa yield was high (570 Kg/ha). Such observations could be seen during 1993, 1994, 1996 and 2000 during which annual mean temperature was low (27.5°C, 27.5°C, 27.6°C and 27.5°C, respectively) while the cocoa yield was high (646 Kg/ha, 623 Kg/ha, 569 Kg/ha and 449 Kg/ha, respectively). It was also observed that when the mean annual mean temperature was above 27.8°C, cocoa yield was likely to decline and vice versa.

As observed in the case of maximum and mean temperature, the relationship between minimum temperature revealed that whenever the mean annual minimum temperature was high, cocoa yield was low and vice versa. For example, annual minimum temperature was high (24.0°C each) during 1983 and 1998, during those years, cocoa yield was high (215 Kg/ha and 412 kg/ha, respectively). In contrast, when the mean annual minimum temperature was low, cocoa yield was high. For example, during 1989 (23.2°C), 1990 (23.3°C), 1992 (23.2°C), 1995 (23.4°C) and 2004 (23.1°C) when the minimum temperatures were low, cocoa yields were high (406 Kg/ha, 412 Kg/ha, 570 Kg/ha, 544 Kg/ha, 577 Kg/ha, respectively). Such situations were predominant in majority of the years (89 per cent).

7.7.2 Heat Unit (GDD) and yield

The relationship between the heat units (Growing Degree Days) and yield is similar to that of temperature as heat unit is a function of mean temperature. It indicated that when the GDD was high, yield was low and vice versa (Fig. 7.10). For example, when the heat unit was high in 1982 (6530°C), 1983 (6632°C), 1987 (6682°C) and 1998 (6580°C), the yield was low (82, 215, 421 and 421 Kg/ha, respectively). In contrast, when the heat units were low in 1993 (6399°C), 1994 (6312°C, 1995 (6461°C) and 2003 (6453°C), cocoa yields were high (646, 623, 544 and 574 Kg/ha, respectively).

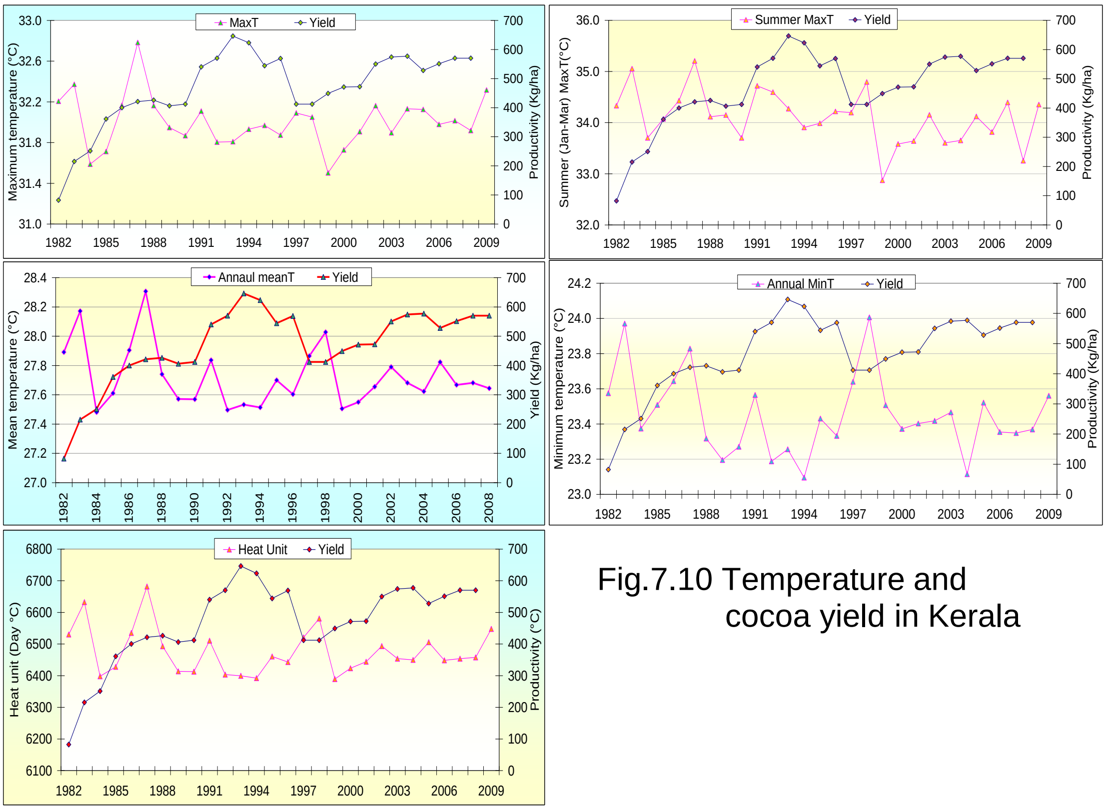


Fig.7.10 Temperature and cocoa yield in Kerala

7.7.3 Temperature and cocoa yield at Vellanikkara

In the case of temperature, the maximum temperature from January to March had a profound influence on annual cocoa yield. Whenever there was an increase in maximum temperature, the annual cocoa yield recorded was low. For example, the maximum temperature recorded between January and March was high (35.3°C) in 1995 against the normal (34.6°C) and the annual cocoa yield was low (42.7 pods/tree). It was also true during 2004 (35.0°C) in which low yield (28.2 pods/tree) was obtained. Whereas, the maximum temperature recorded in 1993 was low (34.0°C) and the annual cocoa yield was high (72.2 pods/tree). Similar was the case in 1997 and 2000 as the annual cocoa yield during the above years were 54.7 pods/tree and 51.4 pods/tree, respectively.

7.7.4 Effect of high summer maximum temperature on cocoa yield at Vellanikkara

The maximum temperature during summer was high (34.6°C) in poor yield years when compared to that of good yield years (34.2°C). A difference of 0.7°C was noticed in April between good and poor yield years (Table. 7.1). It revealed that high maximum temperature during summer is likely to affect the annual cocoa yield adversely.

Table 7.1 Maximum temperature during summer in good and bad yield years

Months	Max. temp. in good yield years					Max. temp. in bad yield years					
	1992	1993	1996	1999	Mean	2004	1998	1995	2003	Mean	Normal
Jan	32.6	32.7	33.1	32.4	32.7	33.4	33.1	32.9	33.2	33.2	32.8
Feb	34.4	34.1	34.7	34.5	34.4	35.2	34.4	35.4	34.7	34.9	34.8
Mar	36.9	35.4	36.4	35.5	36.1	36.5	36.2	37.6	34.6	36.2	36.1
Apr	36.3	35.6	34.6	33.4	34.9	34.8	36.5	36.6	34.6	35.6	35.4
May	33.8	34.4	32.8	30.7	33.0	30.4	34.2	33.5	34.0	33.0	33.8
Mean	34.8	34.4	34.3	33.3	34.2	34.1	34.9	35.2	34.2	34.6	34.5

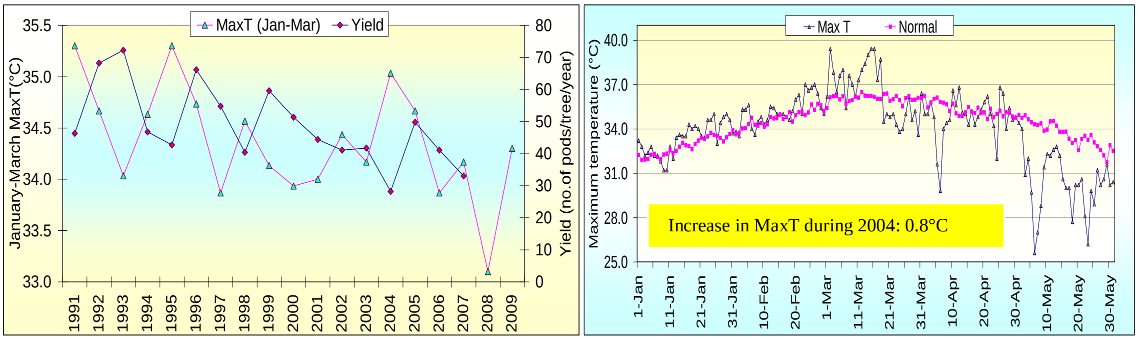
High maximum temperature in general and in particular during summer is detrimental to most of the plantation crops. When crops are exposed to increased temperature under rainfed situations, they are subjected to severe soil moisture stress, if pre-monsoon showers fail. In the event of erratic monsoon and scarce rainfall from post monsoon, situations will become more vulnerable. Such situations will adversely affect the plantation crops production. Yield loss due to unfavourable weather events is a concern in recent years due to global warming and climate change. Hence, an attempt was made to understand the effect of increased temperature during summer and its adverse impact on cocoa yield. Good and bad years were identified based on the yield data and temperature profiles during summer were examined. Murray (1972) reported that the apical dominance was lost when cocoa was consistently exposed to high temperature during summer.

The maximum temperature during summer 2004 showed that there was a sharp rise (1-3°C) during the period from 14th January to 18th March as against the normal maximum temperature of 33°C - 36.5°C (Fig.7.11). Severe water deficit which was prevalent till May led to a drought during summer. Almost all the surface water resources dried up to due to failure of post monsoon across the State of Kerala during 2003-04. In addition, lack of summer showers during February and March worsened the situation and led to early severe drought, which was identical to late summer drought of 1982-83. The reduction in pod yield of cocoa was to the tune of 43 per cent in 2004. A decline of 39 per cent in annual cocoa yield was noticed when large field sample size was considered within the same farm (Amma *et al*., 2006).

Similar results were found in low yields years viz., 1995 (42.7 pods /tree), 1998 (40.4 pods/tree), 2002 (41.1 pods/tree) and 2003 (41.7 pods /tree) when compared to that of annual yield of 49.6 pods/tree. The yield reduction was 14, 19, 18 and 16 per cent, respectively when compared to the mean pod yield.

7.7.5 Heat Unit (GDD) and cocoa yield at Vellanikkara

The relationship between growing degree days (GDD) and yield also indicated similar trend as in the case of maximum temperature (Fig.7.11). For example, the GDD recorded during 1995 was high (6606°C) and the yield during the year was low (42.7 pods/tree). It was also true during 1998 (6533°C) and 2003 (6533°C) as the annual cocoa yield was low and recorded as 40.4 pods/tree and 41.7 pods/tree, respectively. In contrast, the yield recorded during 1992 (68.2 pods/tree), 1993 (72.2 pods/tree) and 1996 (66.1 pods/tree) was high during which low GDD was recorded viz, 6405°C, 6460°C and 6460°C, respectively.



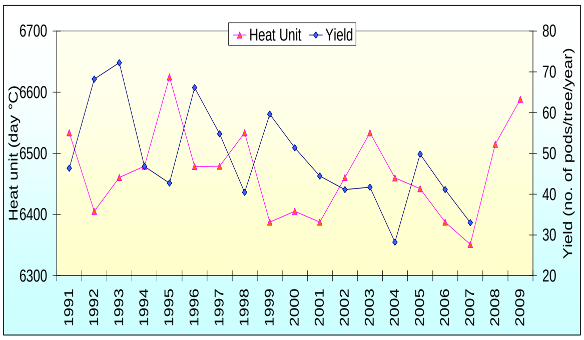


Fig. 7.11 Temperature and cocoa yield at Vellanikkara

7.8 WATER DEFICIT AND COCOA YIELD

It revealed that there exists an inverse relationship between water deficit and yield. The yield was low, when the water deficit was high and vice versa. For example, when the annual water deficit was high in 1983 (451 mm), 1987 (378 mm) and 1990 (365 mm), the yields were low (215 Kg/ha, 421 Kg/ha and 412 Kg/ha), respectively (Fig. 7.12). In contrast, when the annual water deficit was low in 1984 (69 mm), 1988 (225 mm), 1994 (220 mm), 1995 (208 mm), 1999 (187 mm), 2001 (180 mm) and 2008 (187 mm), cocoa yields in the State was high (251 Kg/ha, 426 Kg/ha, 623 Kg/ha, 544 Kg/ha, 449 Kg/ha, 451 Kg/ha and 570 Kg/ha, respectively).

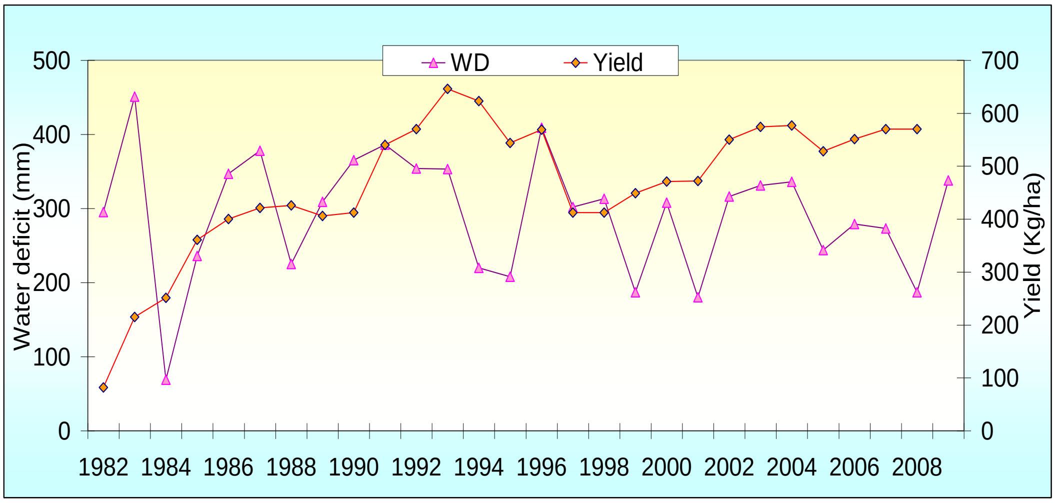


Fig. 7.12 Water deficit and cocoa yield in Kerala

7.9 CLIMATE VARIABILITY AND COCOA YIELD

Increase in area during 1981-90 was very high while the cocoa productivity was very low. The cocoa productivity varied between 330 Kg/ha and 550 Kg/ha. It was low (330 Kg/ha) in 1981-90 when compared to that of 2001-08 (550 Kg/ha). The low cocoa production could be attributed to the indifferent attitudes of cocoa farmers due to price crisis. In addition, warm summer temperatures during the decade might be one of the factors for low cocoa production and productivity. The increase in area, production and productivity in recent years in the case of cocoa could be attributed to adoption of superior clones evolved, technologies and farmer's interest due to stability in price.

Though increase in maximum temperature was evident from 1956 to 2009 and the rate of increase varied between 1.46°C across the highranges and 0.25°C in the midlands of the State, its adverse effects are not seen on cocoa productivity as it was in increasing trend along with temperature. At the same time, such increase in temperature varying between 34.3°C to 35.1°C, the difference of which was 0.8°C in 2004, adversely affected the cocoa yield and the percentage decline varied up to 32 per cent. It clearly indicates that crop like cocoa which is thermo-sensitive may not respond negatively to a steady increase in temperature over a long period of time and at the same time vulnerable to sudden increase in temperature. It again reveals that the crops are more vulnerable to climate variability rather than the climate change through the occurrence of droughts and floods, heat and cold waves and extreme weather events.

Chapter 8

Climate variability and cashew production in Kerala

8.1 AREA, PRODUCTION AND PRODUCTIVITY OF CASHEW IN INDIA

There was a drastic decline in cashew production at the national level in 1997-98 while production was more than half million nuts since 2003-04 onwards (Table 8.1). The area under cashew has increased considerably since last one-and-a-half decade. Similarly, the cashew production at the national level has increased to 6.95 million nuts in 2008-09 from the 3.48 million nuts in 1993-94, registering an increase of 100 per cent.

Table 8.1 Cashew area and production in India from 1995-96 to 2008-09

Year	India		
	Area (ha)	Production (tonnes)	Productivity (Kg/ha)
1993-94	565420	348350	616.1
1994-95	577200	321640	557.2
1995-96	634970	417830	658.0
1996-97	659000	430000	652.5
1997-98	700900	360000	513.6
1998-99	706000	460000	651.6
1999-00	686000	520000	758.0
2000-01	700000	450000	642.9
2001-02	750000	470000	626.7
2002-03	770000	500000	649.4
2003-04	780000	535000	685.9
2004-05	820000	544000	663.4
2005-06	837000	573000	684.6
2006-07	854000	620000	726.0
2007-08	868000	665000	766.1
2008-09	893000	695000	778.3

(Source: Directorate of Cashewnut and Cocoa Development, GoI, Kochi)

The cashew production and productivity were low in the year 1997-98. It could be attributed to adverse weather, which affects the flowering phase very badly. Despite meagre incidence of tea mosquito pest complex in 1997-98, the cashew productivity was low (514 Kg/ha), indicating its sensitivity to weather aberrations. In contrast, the year 1999-2000 was a record year at national level despite heavy damage to cashew plantation in Orissa due to the super cyclone that hit Orissa coast in the end of October 1999. The highest productivity (758 Kg/ha) during the last decade was noted in 1999-00 due to the favourable weather conditions. Despite natural calamities in Orissa, the cashew production in 1999-2000 at national level was one of the best due to favourable weather that prevailed during the reproductive phase of cashew across the Country. The cashew productivity was not to the level of 1999-00 and always less than 700 Kg/ha except in 1999-2000 and reached to more than 700 Kg/ha only in 2006-07, 2007-08 and 2008-09. As a whole, at the national level, the production and productivity of cashew were in increasing trend though inter-annual fluctuations were noticed due to unfavourable weather or incidence of pest and disease. There was an increase in area by 58 per cent from 1993-94 to 2008-09. It reveals that the increase in area was 58 per cent while 100 per cent in the case of cashew production. In the case of cashew productivity, the percentage increase was 26.3. It clearly showed that the area under cashew production and productivity were in increasing trend at the national level during the study period from 1993-94 to 2008-09.

8.2 AREA, PRODUCTION AND PRODUCTIVITY OF CASHEW IN KERALA

The area increase under cashew was 302% from 1952-53 (35410 ha) to 1983-84 (142340 ha). Thereafter, the area under cashew declined to the lowest level of 58380 ha in 2007-08. Accordingly, the cashew productivity showed a declining trend. Decadal area under cashew was increasing from 1952-60 to 2001-08 during the study period. Increase in area was evident from 1952-60 to 1981-90. The lowest area (41.8 thousand ha) was in 1952-60 while the highest area (132.2 thousand ha) in 1981-90. The area under cashew started declining in 1990s and reached the level of 79.4 thousand ha during 2001-08. The area decline was 20 per cent during the last two decades. Shifting of cashew plantations to other economical crops like rubber may be one of the reasons for the decline in area in recent decades.

Cashew production increased from 547500 tonnes in 1952-53 to 1198900 tonnes in 1975-76, registering an increase of 119 per cent. A declining trend was noted from 1976-77 to 1984-85 similar to the declining trend of 1999-00 to 2007-08. !989-90, 1990-91 and 1991- 92 were the good production years during 1990s (Fig. 8.1). The production gradually increased from 1985-86 and reached a peak (108260 tonnes) in 1988-89. Cashew production was declining since then and reached the lowest level of 524020 tonnes in 2007-08. A sharp decline (52 per cent) in cashew production was noticed in the last two decades (1988-89 to 2007-08).

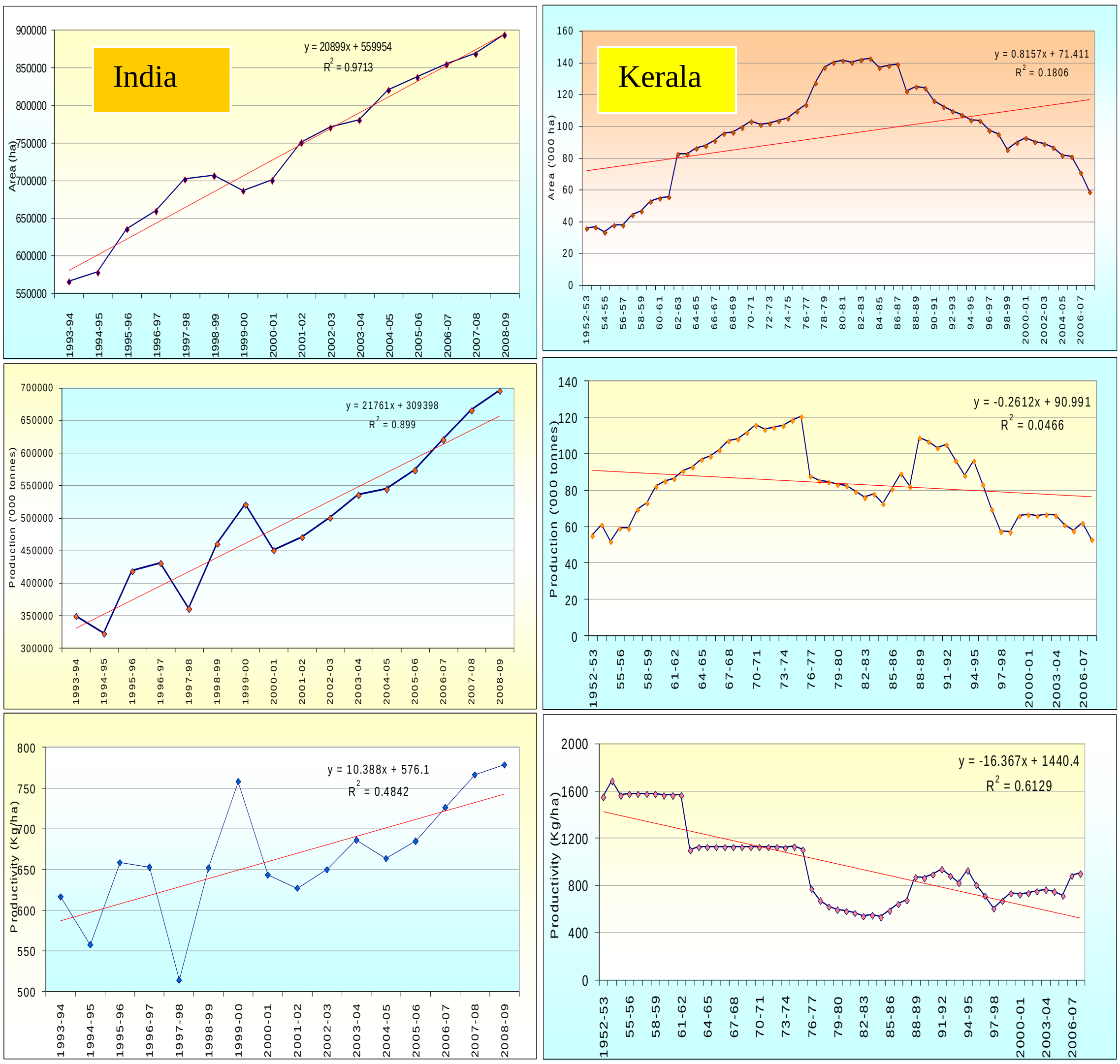


Fig.8.1 Area, production and productivity of cashew in India and Kerala

The decadal production of cashew showed a declining trend since last three decades. The highest production was recorded during 1970s (1961-70) and 1980s (1971-80) each with 100.5 thousand tonnes. The recent decade (2001-08) witnessed for the least production of 61.3 thousand tonnes of raw cashew nuts (Fig.8.2). It revealed that the cashew production was declining gradually since 1970s, indicating that the percentage decline was 29.7 per cent during the last three decades. It may be reminded that during 1970s and 1980s Kerala was the largest producer of raw cashew nuts in India and now it has pushed back to fourth position and is likely to go even back during the ensuing years.

The productivity did not show increase from 1954-55 to 1961-62 (1559 Kg/ha). All on a sudden a decline was noticed in 1962-63 (1069 Kg/ha). The productivity remained more or less the same until 1975-76 (1069 Kg/ha). The lowest productivity level was noticed in 1984-85 (528 Kg/ha). It revealed that as in the case of production, productivity also is declining though increasing trend is seen in recent years.

The cashew productivity over the decades has shown a steep decline. It is quite alarming that the cashew productivity declined from the ever highest value of 1600 Kg/ha during late 50s (1952-60) to the lowest productivity of 659 Kg/ha during 1981-90. Slight improvement in cashew productivity was noticed during 1991-00 and 2001-08 (785 Kg/ha and 773 Kg/ha, respectively). The percentage decline in cashew productivity was 51 per cent over 1950s. In terms of tri-decadal area, an increase of 27 per cent was registered from 1951-80 (83.8 thousand ha) to 1981-08 (106.3 thousand ha). During the same period, tri-decadal production of raw cashew nuts has declined by 14 per cent from 1951-80 (89.6 thousand tonnes) to 1981-08 (977.1 thousand tonnes). The decline in tri-decadal productivity was 42 per cent during the period from 1951-80 (1200 Kg/ha) to 1981-08 (700 Kg/ha).

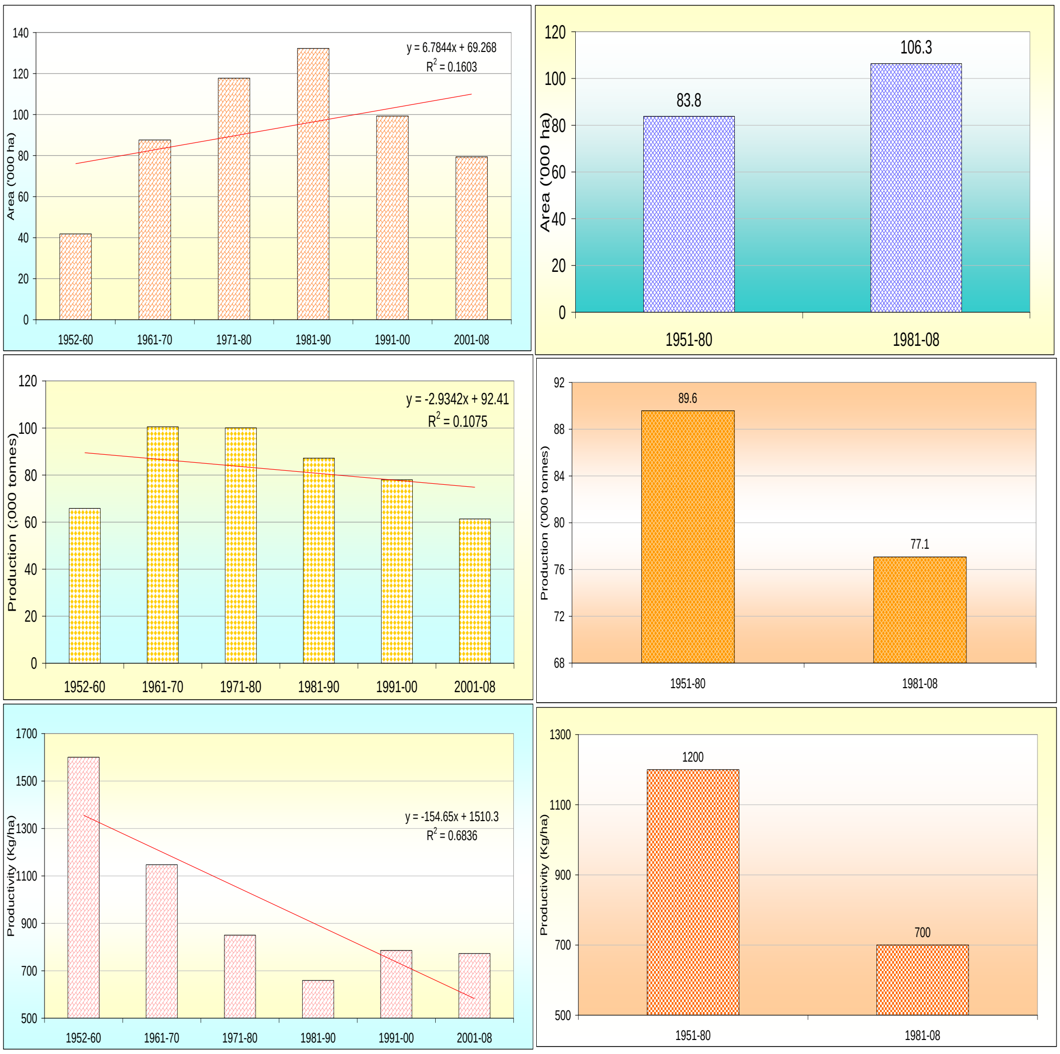


Fig. 8.2 Trend in decadal and tri-decadal area, production and productivity of cashew in Kerala

Farmers' reluctance to cultivate cashew crop due to poor returns and switching over to other profitable crops like rubber is one of the reasons for the decline in cashew area in the State. 1997-98 was a poor yielding year due to unfavourable weather conditions prevailed during the flowering phase of cashew. The yield recorded was only was only 56890 tonnes. Same situation reflected in the national production also. In contrast, incidence of pest complex devastated the cashew plantation along the west coast during 1998-99 though profuse flowering was noticed due to favourable weather. It was more so in Kannur and Kasaragod districts of Kerala, which account for more than 50 per cent of the total cashew production of the State. In 1999-

2000 and 2000-01, a combination of adverse weather and incidence of pest complex adversely affected cashew production of Kerala. There was a drastic decline in cashew yield during the recent years.

8.3 CASHEW GROWING ENVIRONMENT

The total raw cashew nut production in India depends upon the performance of the crop along the West Coast as it accounts for more than 55 per cent of production and 45 per cent of total area. Across the East Coast of India, the area under cashew is 52 per cent and production 41.1 per cent of total. The productivity is much high along the West coast (955 Kg/ha) when compared to that of East Coast (873 Kg/ha). However, Maharashtra is ranking first in area, production and productivity of cashew in the Country (Fig. 8.3). Maharashtra contributes 32.4 per cent to total cashew production from an area of 19 per cent of the total. It has the credit of having the highest productivity of 1500 Kg/ha.

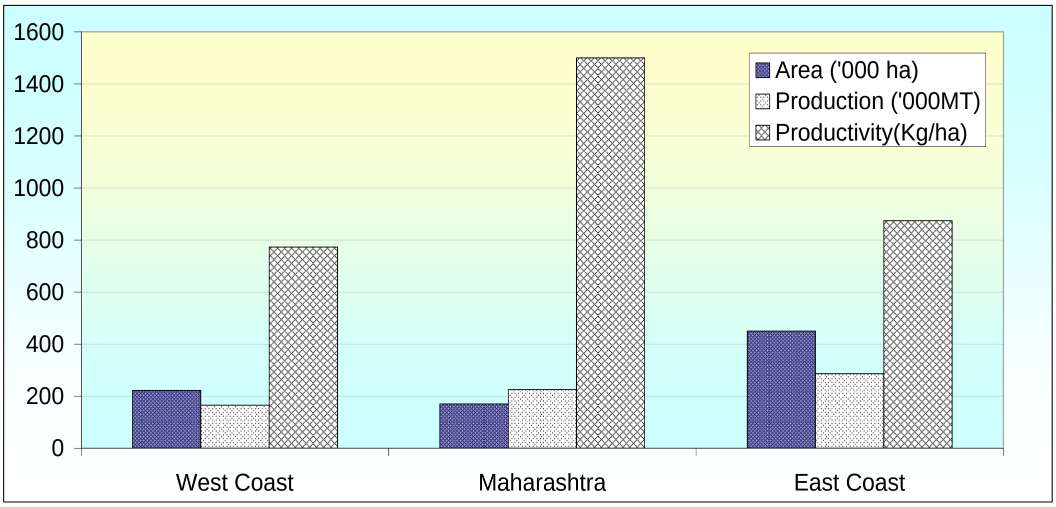


Fig.8.3 Area, production and productivity of cashew across the West Coast, East coast and Maharashtra

Kerala was the leading State in cashew area, production and productivity in the Country in 1990s. Kerala's share to cashew production is only 11 per cent from an area equivalent to that of 8 per cent of the total area under cashew in the Country. Its productivity is comparable to that of national productivity (900 Kg/ha). More than 50 per cent of the State's cashew production is from northern districts viz., Kannur and Kasaragod. The cashew nuts produced from Kannur District is superior in size and quality good, and hence it fetches more value in the international market. This could be attributed to the prevailing weather to which the crop is exposed during the reproductive phase (Fig. 8.4).

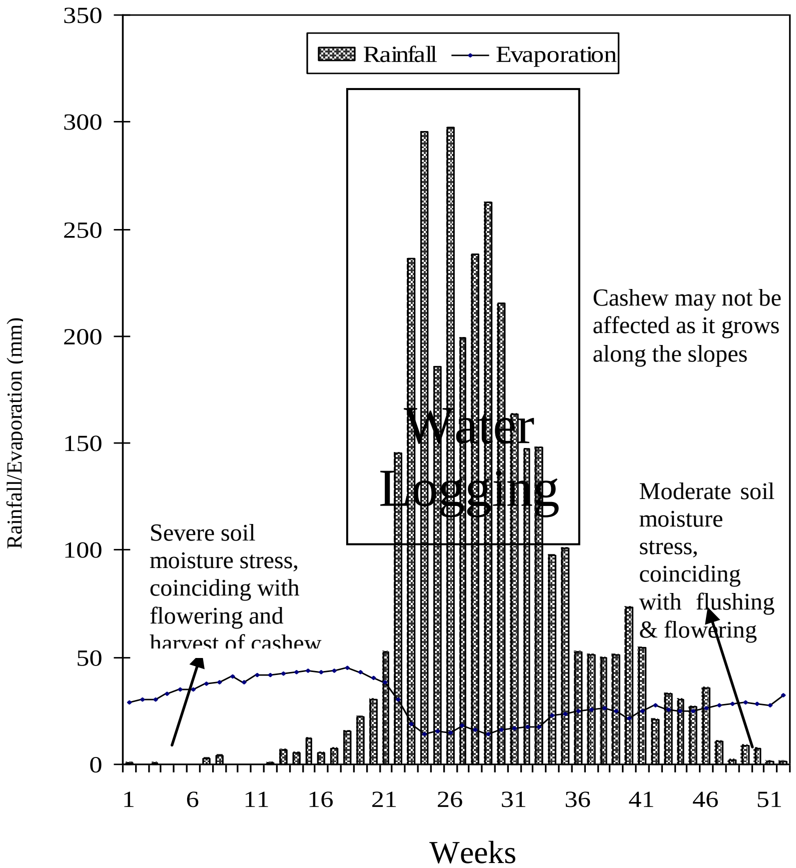


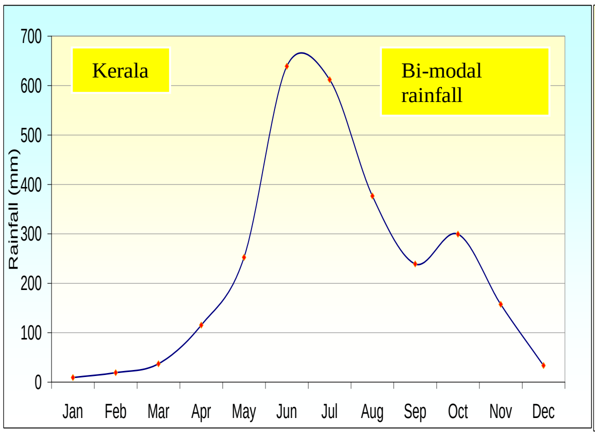
Fig.8.4 Mean weekly rainfall and evaporation at RARS, Pilicode, Kasaragod District

Cashew requires relatively long dry spell with mild winter during the reproductive phase for better flowering. Cashew is a weather sensitive crop.

The reproductive phase is more sensitive to weather. The flowering of cashew may require relatively dry atmosphere with mild winter. The mild winter may be defined as "low minimum surface air temperature ranging between 15^0 C and 20^0 C coupled with more dew nights having moderate dew" in tropical humid climates (Rao *et al.,* 2001). The unusual rains during November and December lead to inordinate delay in reproductive phase of late season types/unknown planting material, which can be detrimental for cashew production as the number of bisexual flowers produced might be less. Weather during the reproductive phase of cashew determines the production. Dry weather is preferred. Continuous and intermittent rains during the reproductive phase of the crop adversely affect the yield and quality of produce. Gopakumar *et al.,* (2005) reported that cashew yield may be poor if it is exposed to humid weather during the reproductive and flowering phase while it is not so under dry weather conditions.

8.4 RAINFALL REGIMES OF CASHEW

The distribution pattern of rainfall in Kerala is such that it is having two peaks one in southwest monsoon season and another one in post monsoon period. However, the bimodal pattern of distribution of rainfall is restricted from south to the central districts where the influence of both the monsoons is felt. Cashew being a crop requires long dryseplI during the reproductive phase, may not perform well under a bimodal rainfall regime. That is why, cashew production is comparatively low in areas where bimodal rainfall is seen such as central and southern Kerala. If the reproductive phase (November to April) of the crop coincides with wet spell, cashew production is adversely affected. That is the reason why, performance of cashew is better in northern Kerala, where unimodal rainfall is felt. Heavy rainfall during June to September followed by weak rainfall, in October-November is the rainfall scenario of Kannur and Kasaragod districts, where cashew is predominantly grown. If the pre-monsoon showers fail most of the plantation crops are subjected to soil moisture stress under rainfed conditions (Fig. 8.5). However, such periods are conducive to cashew as it performs well under dryspell/drought to a certain extent. This is more so in northern Kerala consisting of Kannur and Kasaragod districts where the cashew area is more. More than 50 per cent of the cashew production is from these districts. The cashewnuts produced from these districts are superior in quality and therefore fetches more money in the international market.



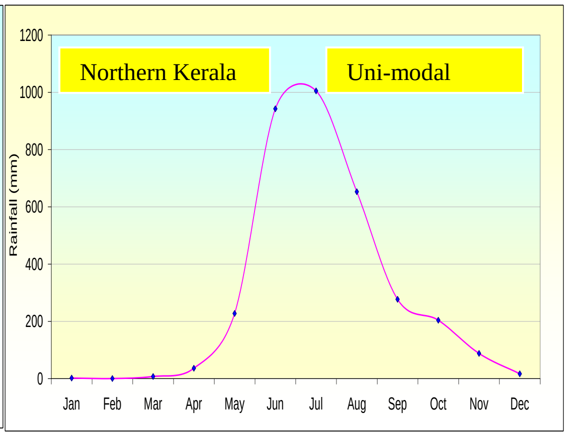


Fig.8.5 Rainfall regimes of cashew

8.5 THERMAL REGIMES OF CASHEW

Though cashew is known as a coastal tree in general, it is grown extensively across the midlands of Kerala. It can thrive well under soil moisture stress conditions and produce better in the midlands of Kerala where the thermal environment is conducive to its growth. The mean annual maximum temperature across the midlands is 32.6°C while it is 22.8°C in the case of mean annual minimum temperature. The mean maximum temperature in the midlands of Kerala where the crop is grown extensively varies between 29.2°C in July and 36.7°C in March. In the case of minimum temperature it varied between 21.3°C in January and 24.4°C in April (Fig. 8.6). The thermal environment in Kerala in general, midlands of the State, in particular is conducive for the growth and development of cashew. Mean maximum temperature during the reproductive phase of cashew (December-March) never crossed 35°C across the West Coast of India. This may be one of the reasons for obtaining larger sized nuts when compared to that East Coast of India where the maximum temperature during the reproductive phase crosses 40°C, which leads to decline in nut size and immature nut fall in cashew. Cashew can tolerate high temperature up to a certain extent, but if exposed to high day temperature (more than 40°C), the performance of cashew may be poor.

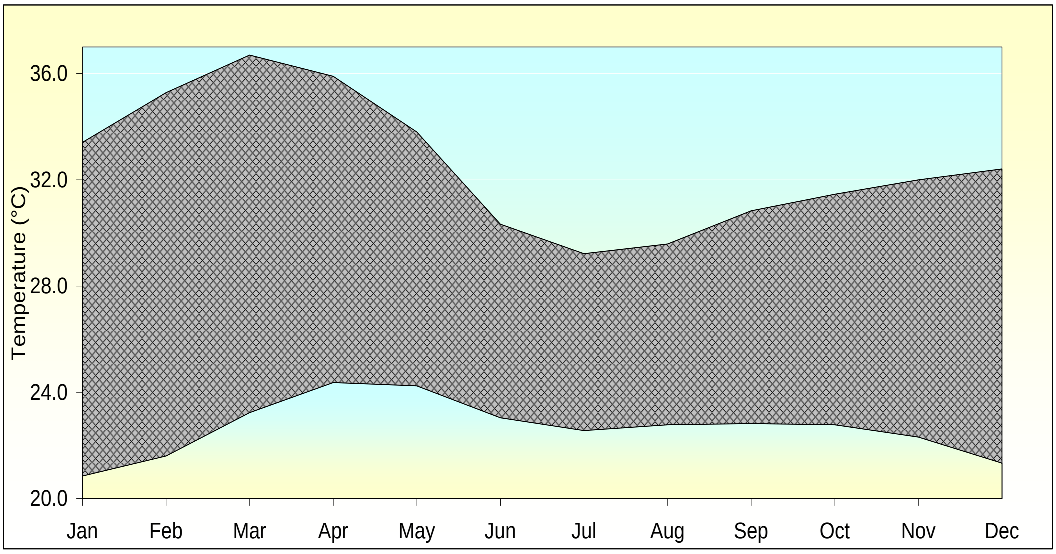


Fig.8.6 Thermal regime of cashew in Kerala

Similarly, exposure to low minimum temperature below 15°C may not be conducive for the crop. That is why the crop is performing better in Kerala, where weather is conducive. Continuous dryspell is required to the crop before the initiation of budbreak. That is why it is called a drought tolerant crop. Wetspell during the reproductive phase of the crop adversely affects the yield.

8.6 EFFECT OF LATITUDE AND ALTITUDE ON FLOWERING OF CASHEW IN KERALA

Hopkins (1938) attempted to express the importance of latitude, longitude and altitude in the distribution and rate of development of plants by means of a “Bioclimatic law”. It may be stated as “A biotic event in north America will, in general, show a lag of four days for each degree of latitude, five degree of longitude and 400 feet of altitude, northwards, eastward and upward in spring and early summer”. In mango, the India Meteorological Department also established that there was a delay in flowering from south to north of India, which generally followed Hopkins’ Bio-climatic law (IMD, 1957). The law stated by Hopkins is sound in biotic events of cashew in tropical monsoon climates under better crop management in rainfed situations, provided the genotype and rainfall distributions are uniform. However, there was a difference in number of days delayed in cashew flowering at each degree of North latitude while the effect of altitude on time of cashew flowering is similar as stated by Hopkins (1938). In tropical monsoon climates, there appeared to a delay of 6 days in cashew flowering at every 1^0 of North latitude and for every 100 m of altitude, the delay in cashew flowering was 3 days (Fig.8.7). The variation in duration of reproductive phase of cashew with latitude and altitude could be explained due to variations in surface air temperature viz., day maximum and night minimum temperatures.

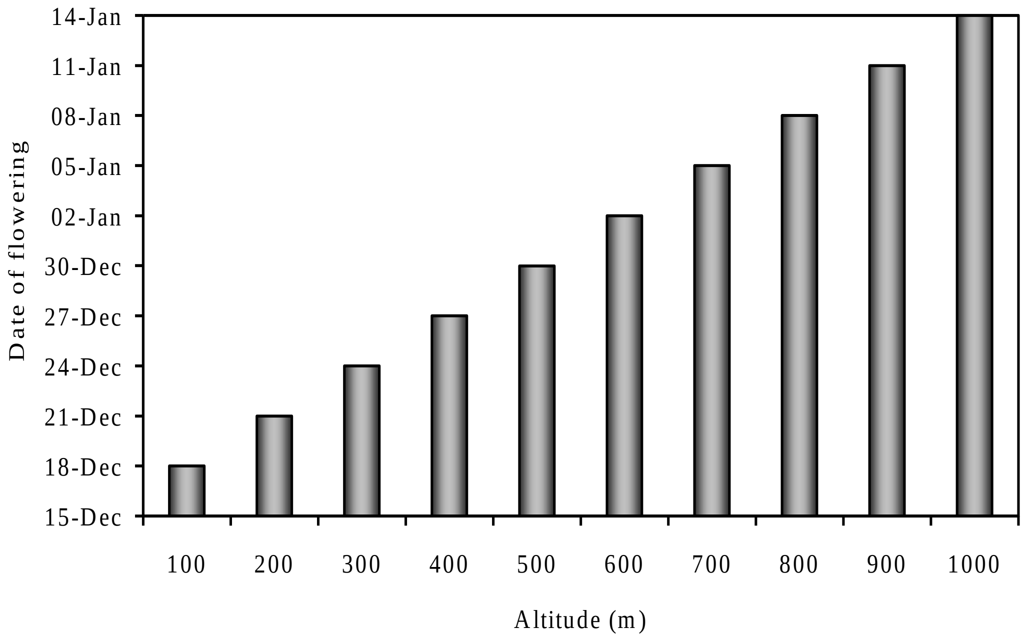


Fig.8.7 Influence of altitude on cashew flowering

8.6.1 Flowering and latitude

The mean flowering date of cashew in Kerala varies from 15th November to 15th January (Fig. 8.8). The flowering date of cashew was 15th November at Kottarakkara (9°16'N) while it was 1st December at Madakkarathara (10°31'N). It was 15th December at Anakkayam (11°01'N) and Pilicode (12°12'N) at Pilicode. The flowering data was 1st January at Puttur (12°45'N) while it was 15th January at highranges in Wayanad (11°37'N). It revealed that the date of flowering varies from location to location depending up on the latitude, location and genotype.

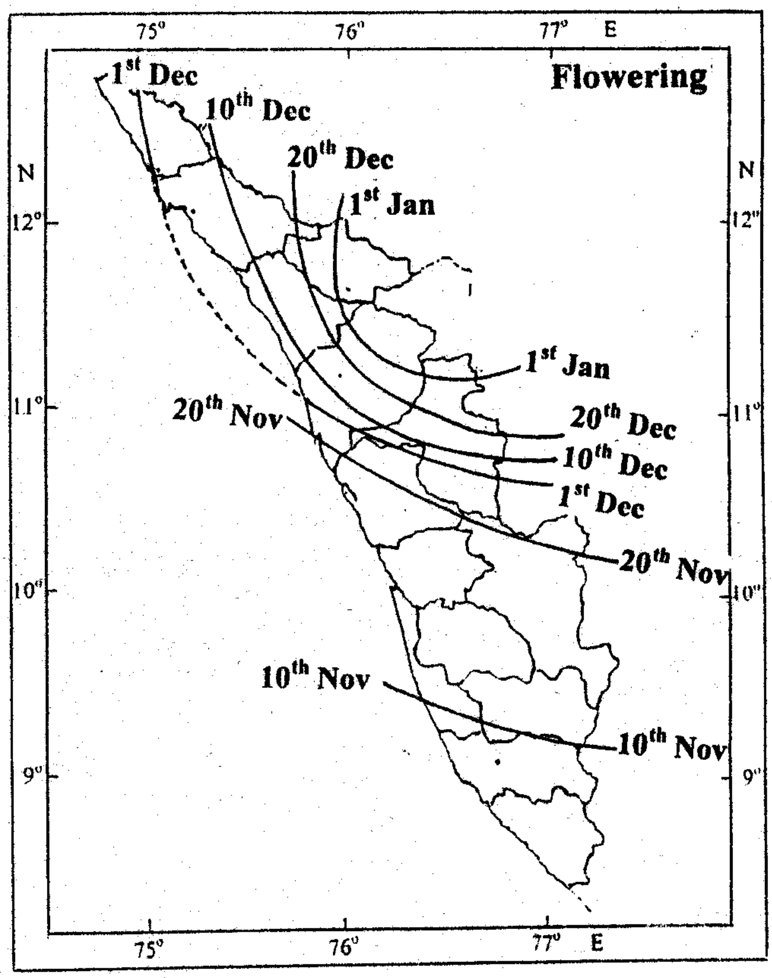


Fig. 8.8 Mean date of flowering in cashew

8.7 RAINFALL AND CASHEW PRODUCTIVITY

In the case of cashew, budbreak initiation commences by September-October after the cessation of post monsoon rainfall depending upon the variety and location. If the post monsoon rain prolongs, vegetative growth phase of cashew also prolongs to November-December. If the rains continue, the favourable environment for the better flowering and nut setting may miss by the crop during December and January. The night temperature may rise beyond favourable limits in such an event. Rao *et al.,* (1999) have observed that untimely rains during November and December and rise in night temperature (>20°C) with less dew nights which coincides with flowering phase in December was detrimental to cashew production by way of altering the flower induction. Therefore, October-November rainfall has profound influence in deciding the final crop harvest, if the vegetative phase continues to November - December.

It revealed that there exists an inverse relationship between rainfall during October - November and cashew yield in more than 50 per cent of years during the study period (Fig.8.9). For example, when the rainfall was low in 1991 (371 mm), and the yield was high (889 Kg/ha). Similar relationships were found in 1995 (376 mm), 2000 (298 mm) and 2008 (517 mm) during which the cashew yield was high (924 Kg/ha, 733 Kg/ha and 897 kg/ha, respectively). In the remaining years, when the rainfall increased a corresponding increase in yield also was noticed. Similar pattern was noticed in the case of rainfall during October as well as November months. As the yield is a complex one to assess, the one to one relationship of weather and yield could not be evident as expected.

In the case of summer rainfall (March-April), the inverse relationship between rainfall and yield was more prominent. 68 per cent years during study period exhibited such trend. When the summer rainfall (March-April) was high (504.7 mm), cashew yield was low (96.7 Kg/ha). Similar trend were seen in 1990 (502.6 mm), 1992 (623.4 mm) and 2002 (751.5 mm) during which the cashew yields were low (52.7 Kg/ha, 44 Kg/ha, 93.2 Kg/ha and 124.1 Kg/ha), respectively.

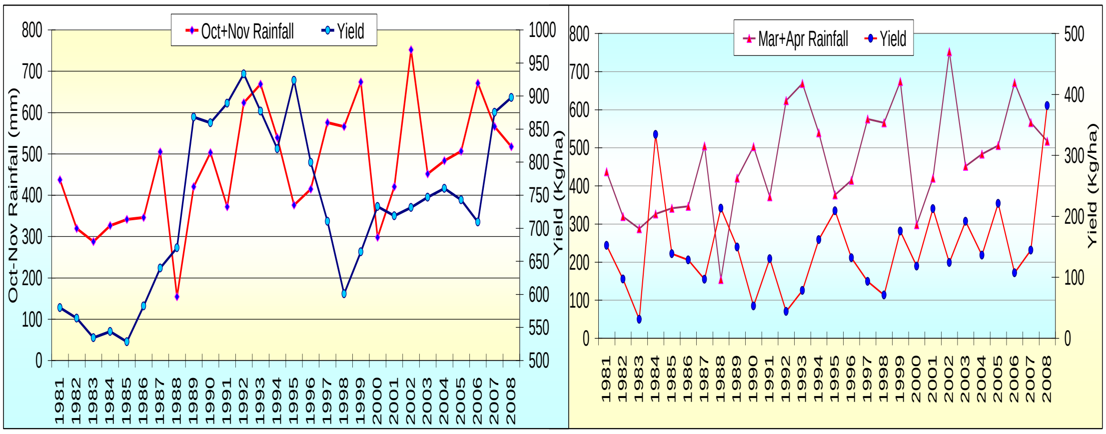


Fig.8.9 Rainfall versus cashew yield

8.8 TEMPERATURE AND YIELD IN CASHEW

Cashew is a sun loving and heat tolerant crop. That is why it is mostly grown in the tropical belt. Though the crop can tolerate high temperature and low temperature to a certain extent, excessive day temperature and very low night temperature may be harmful to the crop. In the humid tropics like Kerala, thermal environments are suitable to the growth and development of cashew. As the vegetative phase of the crop starts by September - October, nuts will be ready for harvest by March/April. Invariably the harvest will be over before the onset of monsoon. Better flowering determines good harvest, if there is no pest attack coupled with favourable weather. As the flowering commences in December through February, night temperature during December has profound influence in determining the flowering characteristics. Rao (2002) reported that cashew requires mild winter for better flowering and nut setting. Mild winter may be defined as “low minimum surface air temperature ranging between 16 and 20°C coupled with more dew nights having moderate dew” in humid tropics.

Minimum temperature during December could explain the yield variability up to 21 per cent. It also revealed that in 67 per cent of the years under study, an inverse relationship with yield was observed. (Fig.8.10).

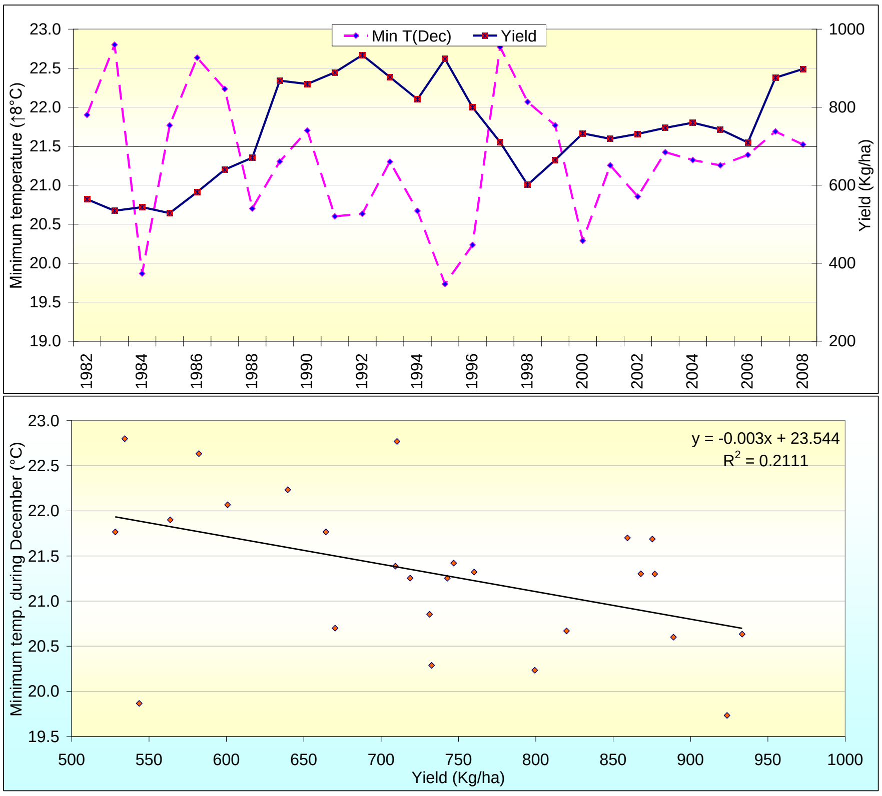


Fig.8.10 Relationship between cashew yield and minimum temperature during December

8.9 YIELD FORECASTING OF CASHEW

Based on the cashew production and climatological data for the State as a whole, crop weather relationships were worked out to understand the effect of temperature and rainfall on cashew production. Rainfall during October, November, March and April and minimum temperature during December could explain the variance of cashew yield up to 82 per cent. The linear regression equation is as follows:

The equation is as follows:

$$Y = 2467.28 + 0.33708^{*}\ Mar + 0.0964467^{*}Apr + 0.448096^{*}Oct + 0.622225^{*}Nov - 92.3927^{*}\ MinT\ Dec\ (R^2 = 0.82)$$

However, the relationships between weather parameters and cashew yield need to be re-examined under the scenario of drastic decline in area under cashew.

8.10 DROUGHT AND CASHEW PRODUCTIVITY

The rainfall distribution across the cashew tract of West Coast is uni-model, followed by prolonged dry spell from November and can extend up to May, if pre monsoon showers fail. The dry spell from October/November to April/May coincides with the reproductive phase of cashew, resulting moderate to severe soil moisture stress across the West Coast. This pattern is predominant in coastal districts of northern Kerala. The cashew tract in Maharashtra experiences prolonged dry spell of five to seven months as rain ceases by the end of October and the crop experiences severe soil moisture stress. However, in the West Coast during the dormant phase (June to September) of cashew no soil moisture stress is seen. Though the reproductive phase of cashew is under soil moisture stress, cashew plantations at different locations (Kottarakkara, Madakkathara, Anakkayam, Pilicode, Puttur and Vengurlae) across the West Coast are healthy. Similar was the situation in Orissa and West Bengal where cashew is cultivated across the East Coast.

In contrast, Tamil Nadu receives more rains from September to November due to the influence of Northeast monsoon. It may, sometimes extend up to December over Tamil Nadu where cashew is grown. Across the cashew tract of Andhra Pradesh, the monthly rainfall may exceed sometimes evapotranspiration from August to October depending upon the location. Cyclones are not uncommon across the East Coast (Tamil Nadu, Andhra Pradesh and Orissa) during October and November, which bring copious rains and uproot cashew plantations due to heavy wind speed. Also, rains may extend up to November due to cyclones, which are not uncommon over the coastal belt of Andhra Pradesh. The reproductive phase of cashew from

February to May in these areas is under soil moisture stress as the crop is grown under sandy to sandy loam with poor water holding capacity. The cashew at Chintamani (Karnataka) is always under soil moisture stress throughout the year as rainfall was less than evapotranspiration round the year except a few weeks between September and November. Despite of the above fact, cashew plantations are better and comparable at Chintamani (Karnataka).

The cashew yield at Vengurlae was the highest (18.5 Kg/tree), even though the crop is under moderate to severe soil moisture stress for five to seven months during its reproductive phase. The cashew yield of the superior varieties was 10.5 Kg/tree at Madakkathara, where a prolonged dry spell of three to five months is seen during the reproductive phase of cashew (Fig.8.11).

Bhubaneswar and Vriddhachalam recorded 12.8 Kg/tree and 8.9 kg/tree, respectively where the maximum temperature during the nut setting and development phase (March to May) is high and considered to be a constraint occasionally under severe soil moisture stress. At Chintamani, the cashew yield was 8.1 Kg/tree where crop is under soil moisture stress for a prolonged period unlike at other cashew growing locations.

It is evident that cashew productivity was relatively low where the crop is under soil moisture stress for eight to ten months as the case at Vriddhachalam and Chintamani. However, the yield was much better at cashew research stations where cashew is grown under rainfed conditions in better crop management situations when compared to that of country's average (less than 4 Kg). Also, the cashew production is relatively high in Kannur and Kasaragod districts in Kerala, where prolonged dryspell is noticed from November to March, coinciding with the reproductive phase of cashew. At the same time, the yield was low whenever intermittent rain spells received from November to May across west and east coasts of India. Immature fruit drop was noticed if wet spells are seen in March/ April, which lead to poor yield and quality.

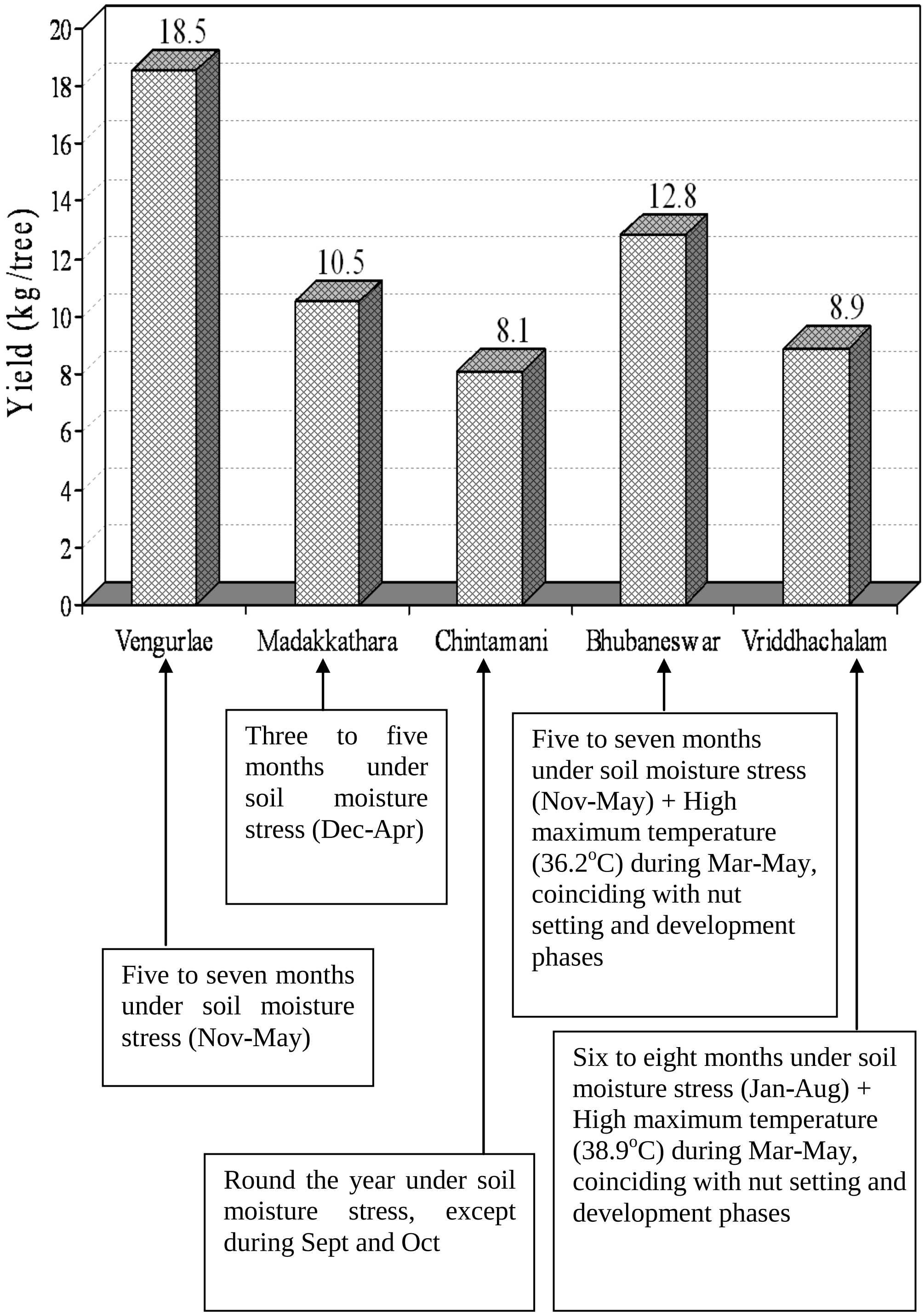


Fig. 8.11 Drought and cashew productivity

From the above, it is understood that cashew experiences moderate to severe soil moisture stress across west coast under rainfed conditions and prolonged further across east coast as rain received is late and it is below crop water need. At Chintamani, cashew almost suffers due to soil moisture stress round the year except a few weeks between September and November. With all the supporting data on the performance of cashew under dryspell/drought, it can be inferred that cashew thrives well under drought situation. In fact, cashew is exposed to dryspell/drought during its reproductive phase and yields better. However, the abnormal drought situation affects cashew yield very much under rainfed conditions. This is possible if the duration of dryspell is prolonged from the normal as the varieties/cultivars are susceptible to abnormal severe soil moisture stress. The varieties/cultivars are tolerant to soil moisture stress under normal rainfed conditions due to their adaptability over a period of long time, beyond which they may fail to yield at the desired levels.

Also, the cashew yield and its quality are affected due to prevalence of high maximum temperature (35^0 C and beyond) during the reproductive phase of cashew (flowering/nut setting to harvest) in a situation where prolonged abnormal drought is noticed. The above situation is noticed across east coast at Vriddhachalam, Bapatla, Bhubaneswar and Jhargram. Sometimes, the maximum temperature shoots up to 42^oC during the nut development period across the East Coast. However, it is not the case across the West Coast. The moderate (30-33^oC) maximum temperature that persists across West

Coast during the reproductive phase may be ideal for better nut development and its quality. However, at Madakkathara in Kerala along the West Coast, high wind speed during November and December and maximum surface air temperature beyond 35 degree Celsius during summer (February-April) may be limiting factors for obtaining potential yields in cashew. It needs further examination. Also, the physiology of crop is to be totally understood to find out the mechanisms, which are working internally in favour of drought tolerance in cashew.

8.11 ENVIRONMENTAL CONSTRAINTS OVER KERALA

The benevolent and malevolent effects of cashew environment across Kerala are highlighted separately in Table 8.2, as it plays a major role in cashew industry. As a whole, the incidence of pest complex is the threat to cashew production over Kerala. In few pockets like Palghat and Thrissur, the adverse effects of high wind speed and the maximum surface air temperature beyond 35 degree Celsius during the reproductive phase on nut yield and its characteristics are yet to be understood. Similarly, lack of mild winter and occasional wetspells towards south of Kerala may also hinder cashew production.

Table 8.2 Environmental constraints over Kerala

Environment		Effect
PLANT		
1. Planting Material	Pedigree & Senile	Malevolent
2. Crop management including crop Protection measures	Very poor	Malevolent
3. Dormant phase	No soil moisture stress, Exposed to low solar radiation due to heavy rainfall	Benevolent/ Malevolent
4. Reproductive phase	Soil moisture stress	Malevolent
5. Flowering	December/January	Early season type may escape pest complex-Benevolent
SOIL		
1. Soil	Very deep and well drained laterites; OC-marginal, N-low to medium, K_2O-low	
2. Topography	Slopes	
CLIMATE		
1. Climate	Coastal	Benevolent
2. Annual rainfall	2000 to 3600 mm	Malevolent
3. Max. Temperature	< 35°C (30-35°C opt.)	Benevolent
4. Min. Temperature	>15°C (15-20°C opt.)	Benevolent
5. Soil temperature	Moderate	Benevolent
6. Sunshine	Around 2700	Benevolent
7. Relative humidity	70 to 90%	Malevolent
8. Wind speed	Low to moderate except over Palghat and Thrissur	Benevolent- It is doubtful in case of Palghat and Thrissur districts where wind speed is high
IRRIGATION	No summer irrigation	Malevolent
PEST & DISEASES		
1. Tea mosquito	Moderate to severe	Malevolent-threat to cashew production

8.12 EFFECT OF STRONG EASTERLY WIND ON CASHEW PRODUCTION ACROSS THE CENTRAL KERALA

In the Central region of Kerala, viz., in Thrissur and Palakkad districts, a gradual increase in wind speed is noticed from the second fortnight of November to mid February or till the end of February. This is a part of the global wind systems. The wind as it passes through the Palakkad gap of the Western Ghats, gains momentum and blows as easterly wind towards west. The influence of the wind is felt up to coastal areas of Thrissur district. Average daily wind speed quite often crosses 10 Km/hr where as the mean annual wind speed is 5 Km/hr. Instantaneous wind speed is much higher than the average wind speed during these periods. To understand the trend in wind speed during flowering phase of cashew (November to February) over the Central region of Kerala, data on wind speed was analyzed for the period from 1983 to 2009**.** It revealed that mean annual wind speed over Thrissur is declining by 2.3 Km/hr per year. The mean wind speed during the flowering phase of cashew (November to February) also showed a declining trend (decline by 3.5 km/hr /year) during the 27 year period from 1983 to 2009.

In order to understand whether there is any increase in wind speed during the recent decades, mean annual wind speed was examined for the period 1996-2009. Interestingly, it was found that the mean annual wind speed has been increasing at the rate of 1.0 Km/hr per year. Wind speed during the flowering phase of cashew (November to February) also exhibits an increasing trend (at the rate of 1.37 Km/hr per year) during the period 1996-97 to 2008-09 (Fig.8.12). In all the months viz., November (Increase: 1.4 Km/hr), December (increase: 1.9 km/hr), January (Increase: 1.2 Km/hr) and February (Increase: 0.92km/hr), wind speed showed an increasing tendency. It was interesting to note that there was no increasing tendency in wind speed during the flowering phase of cashew during 1983-84 to 1995-96. It is true in the case of entire data period from 1983-84 to 2008-09. It clearly reveals that wind speed from November to February which coincides with the flowering period of cashew is in increasing since last one-and-a-half decade over the Central region of Kerala.

It has been established that that the yield loss would be about 20 about per cent in *Mundakan* paddy due to the strong wind prevails in the Central part of Kerala during November to February. Rao (2002) reported that strong wind during the flowering phase of cashew prevailing in the Central region of Kerala may be an environmental constraint in obtaining potential yield. The strong wind prevails during the peak flowering of cashew during November to

February may be able to wither away the flowers, and thereby causes yield loss. Strong dry wind also causes flower infertility and flower scorching.

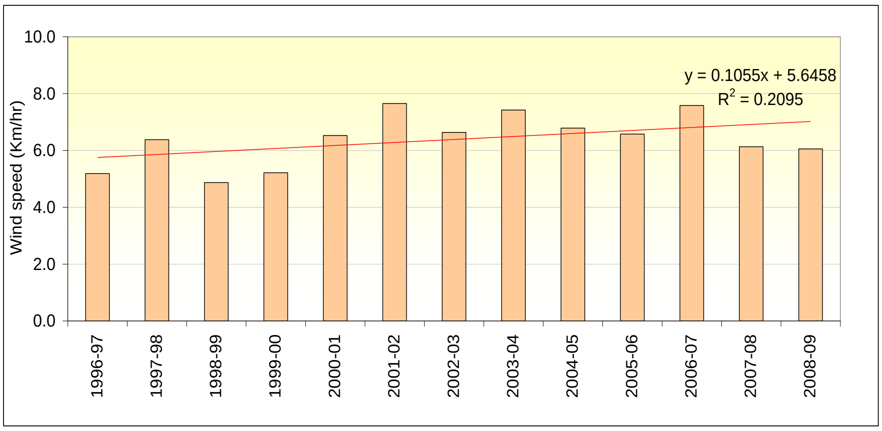


Fig. 8.12 Wind speed during the flowering phase of cashew in Central Kerala

However, effect of increased wind speed on yield loss of cashew is yet to be quantified. The wind never caused mechanical damages to cashew plantations as noticed in the East Coast during cyclonic storms. Hence, as far as Kerala is concerned, mild wind speed is having a favorable effect on cashew production. Whereas strong wind during the flowering phase of cashew is a constraint for cashew production in Palakkad and Thrissur Districts. Further probe in this direction is needed to quantify the yield loss due to strong easterly wind.

8.13 CLIMATE VARIABILITY AND CASHEW

There was a significant increase of 0.4°C in maximum temperature since 1981 onwards while it was not so in the case of minimum temperature. At the same time, the increase in maximum and minimum temperature was so evident that the decade 1981-90 was the warmest decade and it reflected in mean surface air temperature. The warming Kerala is evident since 1981 in terms of temperature and increase in its range (the difference between

maximum and minimum temperature). The increase in temperature was so evident that it was significant from one climatic period to (1951-80) to another (1981-2009). In contrast, the decline in rainfall was seen during the same period and it was more so in the decade 1981-90. Probably, the decline in rainfall might be the reason for increase in temperature during the decade 1981-90. Decline in rainfall and increase in temperature resulted to increase in aridity and decline in moisture index, led to shift in climate from B4 to B3 within the humid climate. Such situations led to increased number of droughts from previous tri-decade to present tri - decade (Figs. 8.13 & 8.14). The change in climate events led to decline in cashew production (Fig. 8.15). There was a decline of 52% in cashew productivity. The percentage decline in cashew productivity was the highest (59%) in 1981-90 due to the warmest and drought conditions in the form of decline in rainfall and increase in temperature.

Of course, the decline in cashew productivity was evident due to decline in cashew area since last two decades. Of course, the decline area was the major factor for decline in cashew production since last 30 years. At the same time, the decline in cashew productivity could be explained due to warming Kerala. Therefore, the inter-annual variation in cashew productivity decline over a period of time can be attributed to climate variability and climate change.

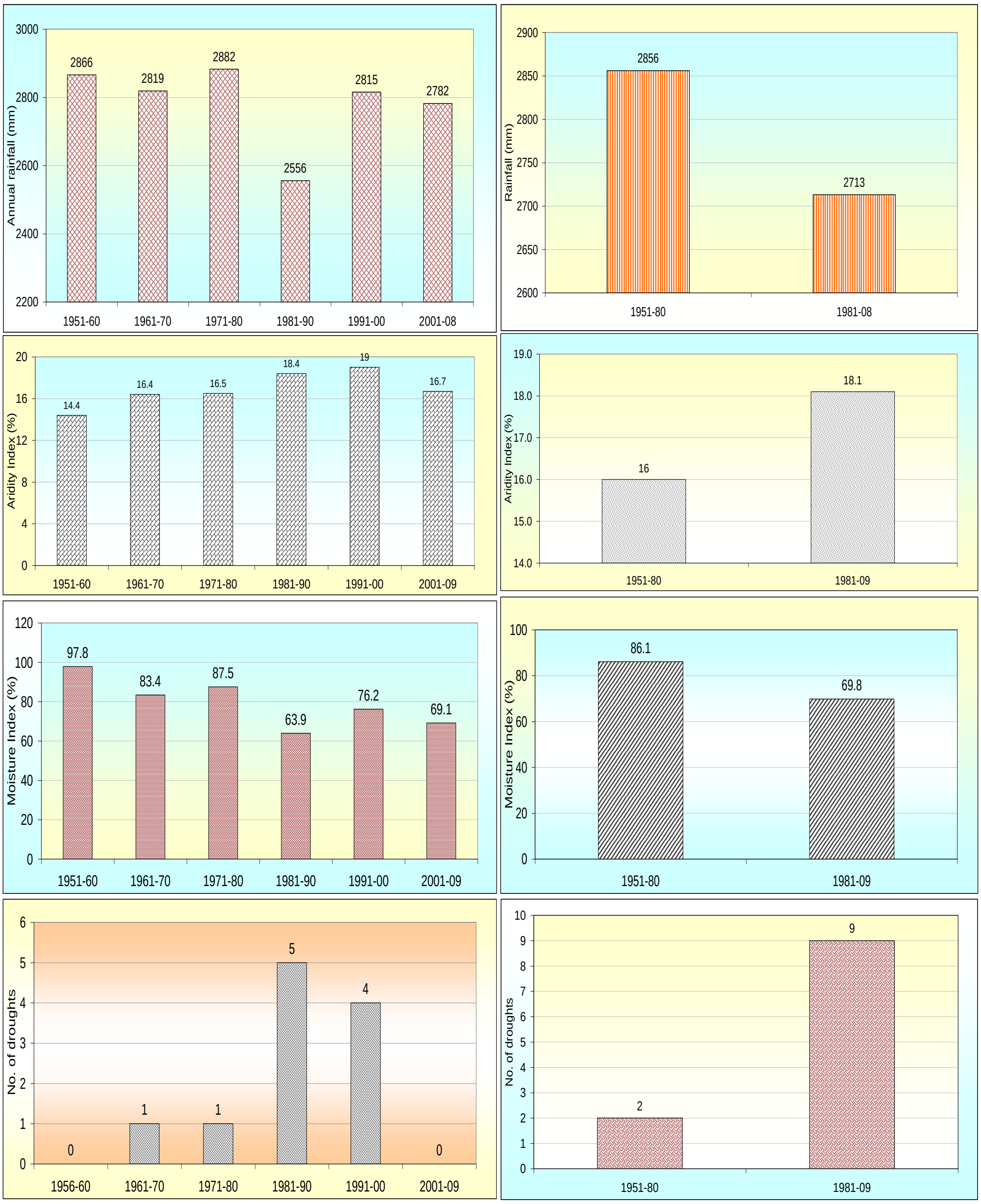


Fig.8.13 Decadal and tri-decadal trend in rainfall, aridity index, moisture index and number of droughts

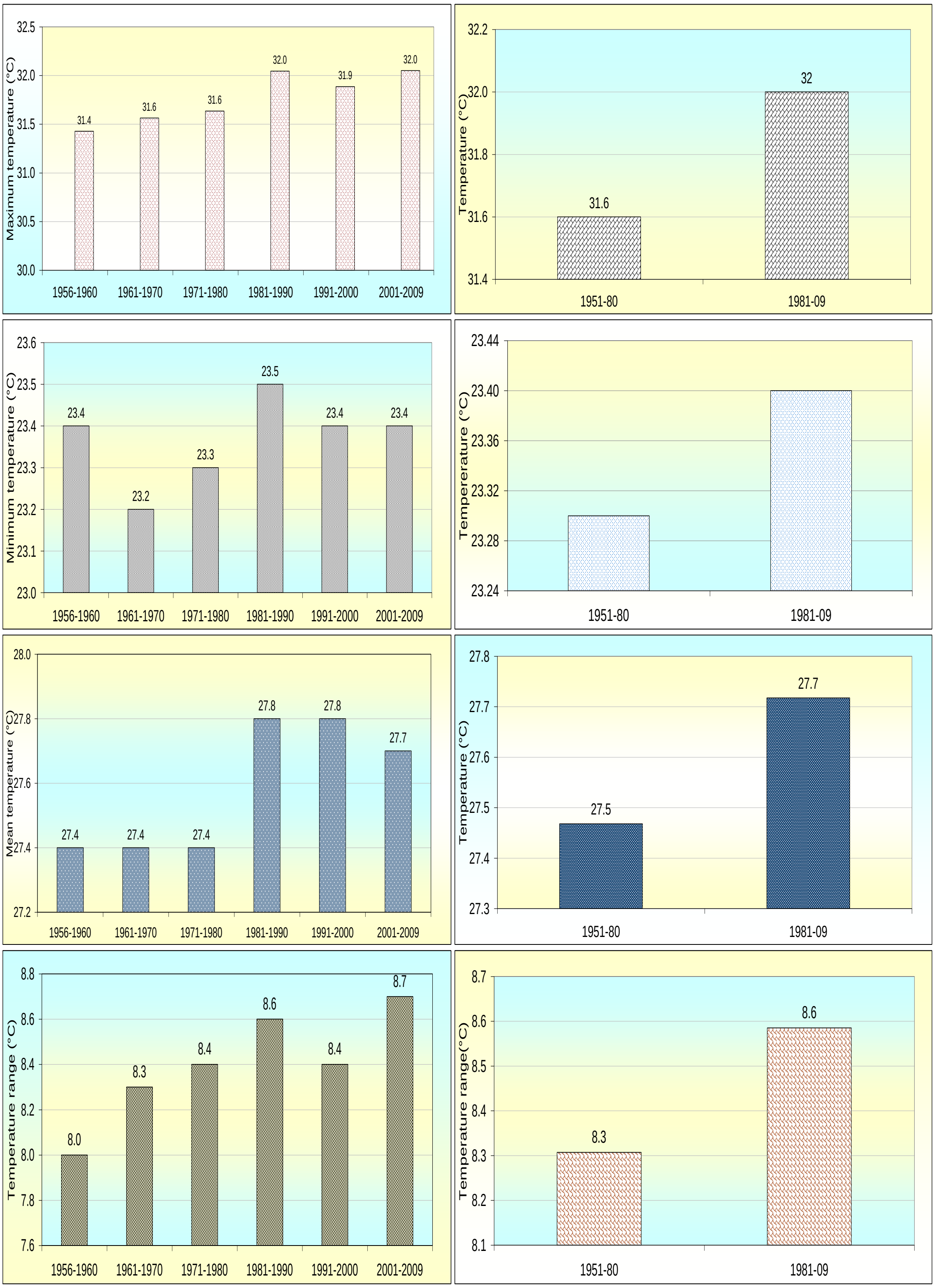


Fig. 8.14 Decadal and tri-decadal variations in temperature

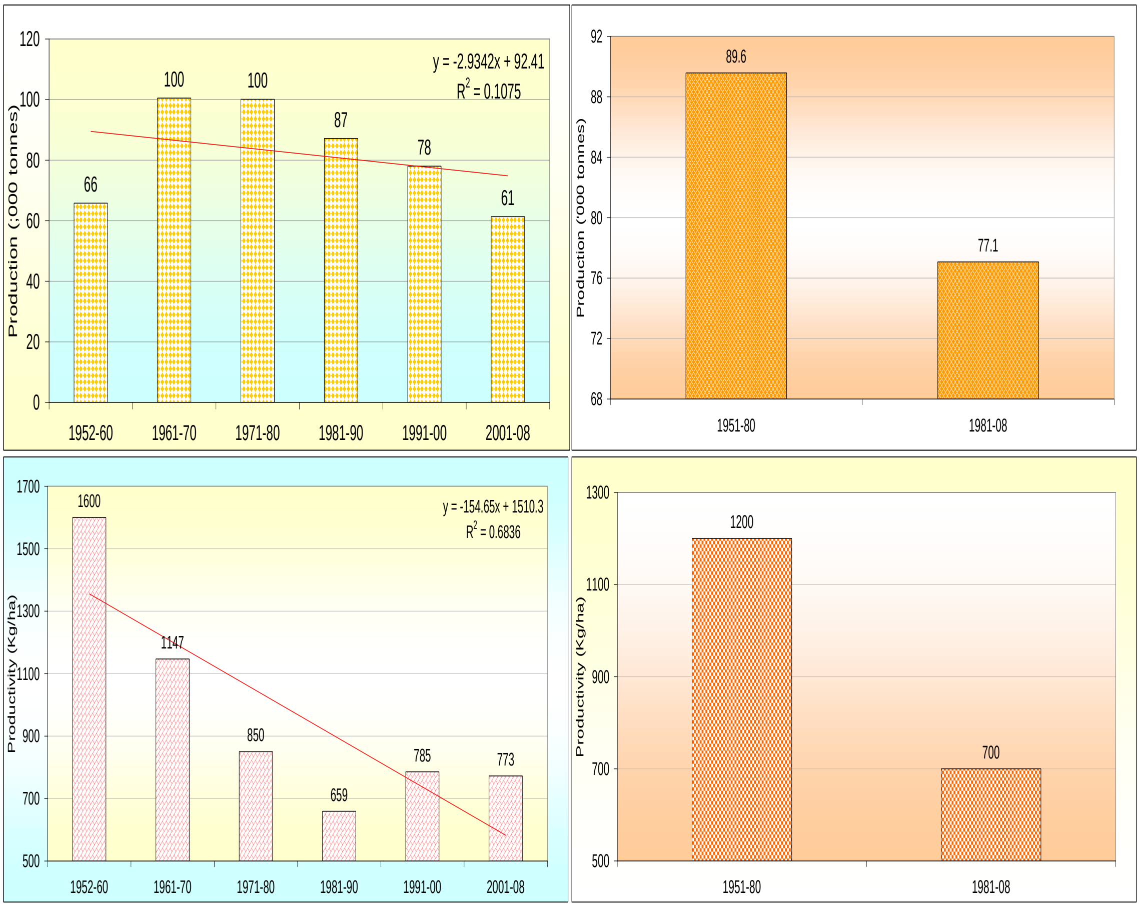


Fig. 8.15 Decadal and tri-decadal production and productivity of cashew

Chapter 9

Climate variability and Rubber production in Kerala

9.1 TREND IN AREA, PRODUCTION AND PRODUCTIVITY

Area under rubber was just 62.6 thousand ha in 1952-53. It has increased by 727 per cent and reached 517.5 thousand ha in 2008-09. The area under rubber has been steadily increasing over the years (Fig. 9.1). Decadal area indicated that it was in increasing over the decades. During 1952-60, area under rubber was 83 thousand ha which has increased to 490 thousand ha in 2001-09. The percentage increase in area was more (79%) from the decade 1952-60 to 1961-70, followed by 1971-80 to 1981-90 (56 %) and 1981-90 to 1991-00 (41 per cent). The increase in area was the least in the recent decade 2001-09 (9.6 per cent). Tri-decadal area has increased significantly by 179 per cent.

Rubber Production also has been in upward trend since 1952. Increase in area was tremendous over a period of six decades. The increase in production was 3960 thousand tonnes from 1952 to 2009. Decadal production was in increasing trend. The lowest production (21 thousand tonnes) was in the decade 1952-60. The production during the decade 2001-09 was 684 thousand tonnes. The percentage increase in decadal production was the highest in 1971-80 (155 per cent), followed by 1991-90 (141 per cent) and 1961-70 (114 per cent). The least increase in production was recorded in

2001-09 (51 per cent), followed by 1981-90 (63 per cent). The tri-decadal production of rubber has registered an increase of 589 per cent.

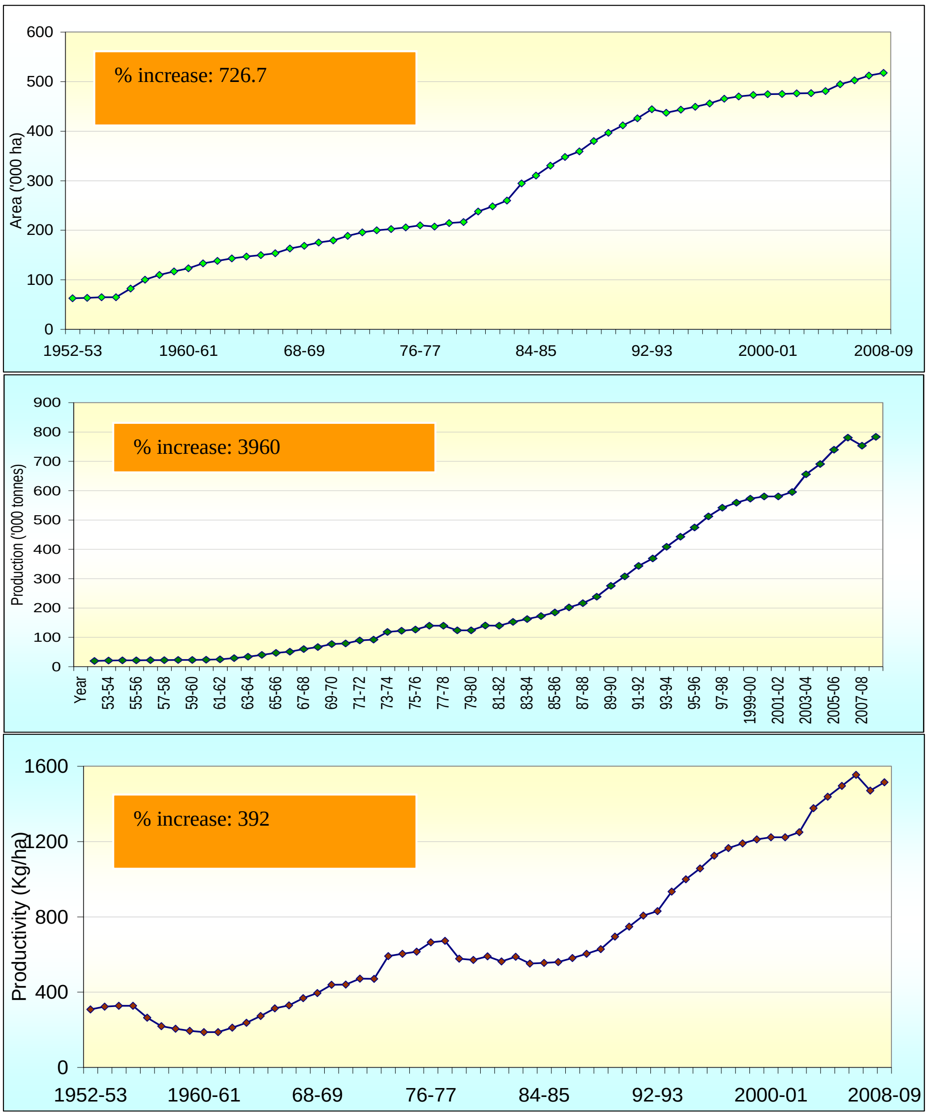


Fig. 9.1 Area, production and productivity of rubber in Kerala

As in the case of production, productivity of rubber has been increasing over the decades. The average productivity of rubber during 1952-60 was only 271 Kg/ha. It has reached 1393 Kg/ha in 2001-09. Tri-decadal productivity also has registered an increase of 155 per cent (Fig.9.2)

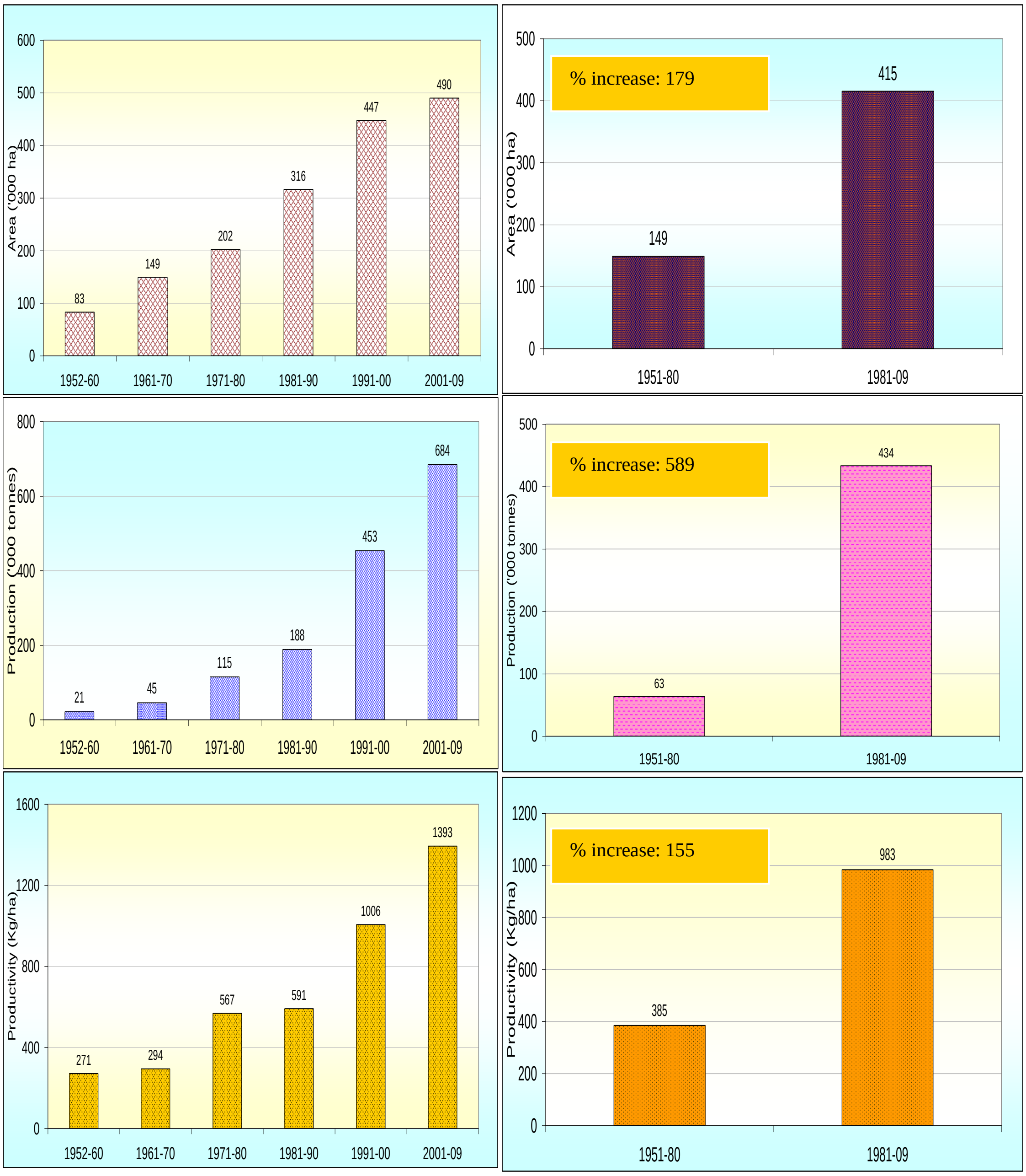
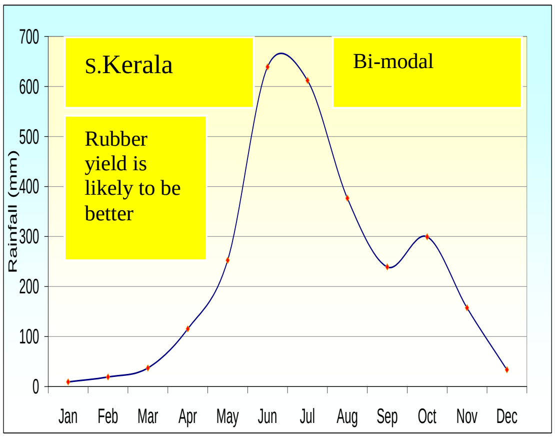


Fig.9.2 Decadal and Tri-decadal trend in area, production and productivity of rubber in Kerala

9.2 RAINFALL REGIMES OF RUBBER

Rubber plants are traditionally grown under rainfed conditions. Irrigation is practiced only in nurseries. Under rainfed conditions, monthly rainfall should be sufficient to meet the water requirement of the crop. In the tropical monsoon climate, the potential evapotranspiration rate is about 4 mm per day (Monteith, 1977) and therefore, an amount of 125 mm per month is considered essential to maintain optimum growth of plants. In traditional rubber growing areas like Kerala, annual rainfall ranges from 1000 to 4000 mm. The distribution pattern of rainfall in Kerala is such that it is having two peaks one in southwest monsoon season and another one in post monsoon period. However, the bimodal pattern of distribution of rainfall is restricted from central and southern districts where the influences of both the monsoons are felt. Rubber being a crop requires well distributed rainfall during its yielding phase may not perform well under a unimodal rainfall regime. That is why, rubber production is comparatively low in areas where unimodel rainfall is seen such as northern districts of Kerala.

Heavy rainfall from June to September followed by weak rainfall in October - November is the rainfall scenario of Kannur and Kasaragod districts. If the pre-monsoon showers fail most of the plantation crops are subjected to soil moisture stress under rainfed conditions. However, such long dry spells are not conducive to rubber as it yields poor under dryspell / drought situation. This is more so in northern Kerala consisting of Kannur and Kasaragod districts where the rubber area is comparatively poor (Fig. 9.3).



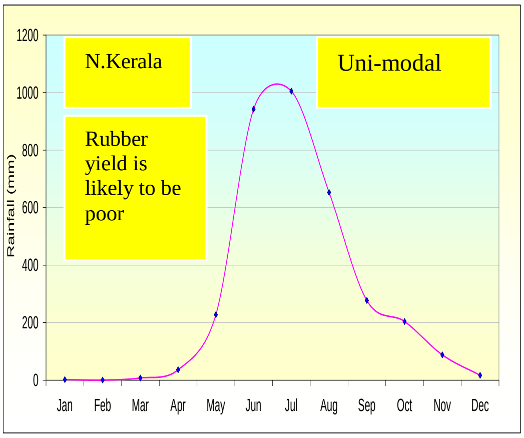


Fig.9.3 Rainfall regimes of rubber in Kerala

9.3 THERMAL REGIME OF RUBBER

Temperature is one of the key environmental factors which influence plant growth. Rubber, being a crop adapted to moderate temperatures, gets affected by extremes in temperatures. Higher temperature results in higher rates of evapotranspiration and thereby to severe soil moisture stress in the absence of rainfall. Rubber is grown extensively across the midlands of Kerala. It can thrive well and produce better in the midlands of Kerala where the thermal environment is conducive to its growth. The mean annual maximum temperature across the midlands is 32.6°C while it is 22.8°C in the case of mean annual minimum temperature. The mean maximum temperature in the midlands of Kerala where the crop is grown extensively varies between 29.2°C in July and 36.7°C in March. In the case of minimum temperature it varied between 21.3°C in January and 24.4°C in April (Fig.9.4). The thermal environment in Kerala in general, midlands of the State in particular is conducive for the growth and development of rubber.

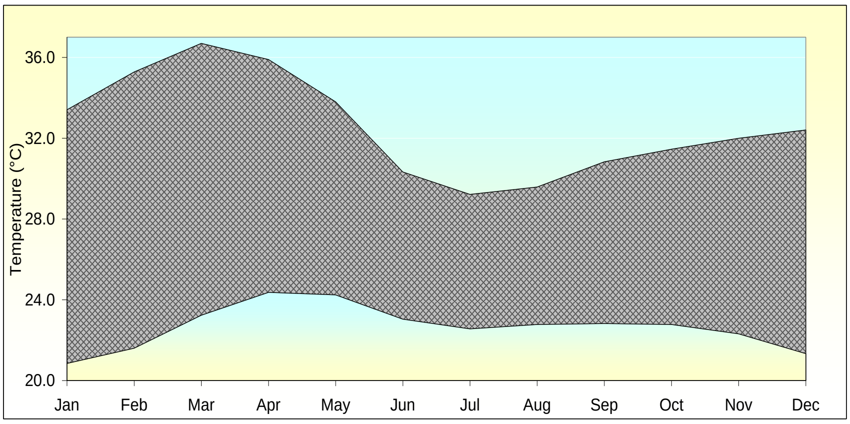


Fig.9.4 Thermal regime of rubber in Kerala

9.4 CLIMATE VARIABILITY AND RUBBER PRODUCTION

The rate of increase in rubber productivity was affected during 1959-63 (-24.3%), followed by 1979-83 (-8.3%), 1984-88 (2.2%), 1999-03 (13.5%) and 2004-08 (18.9%). The percentage decline in productivity of rubber could be attributed to the adverse weather situations prevailed during that period. 1961 was severe flood year as far as Kerala is concerned. Severe flood due to continuous rainfall and more number of rainy days led to low productivity, though it was not very evident from the productivity chart. Continuous rainfall adversely affects rubber production. Tapping is adversely affected in the event of heavy rainfall and extended number of rainy days. Similarly, during 1979-83 and 1984-88 there was a decline in the rate of increase of yield (Fig. 9.5). 1981-90 was the warmest and hottest decade in Kerala, which might have influenced adversely the rubber yield during that decade.

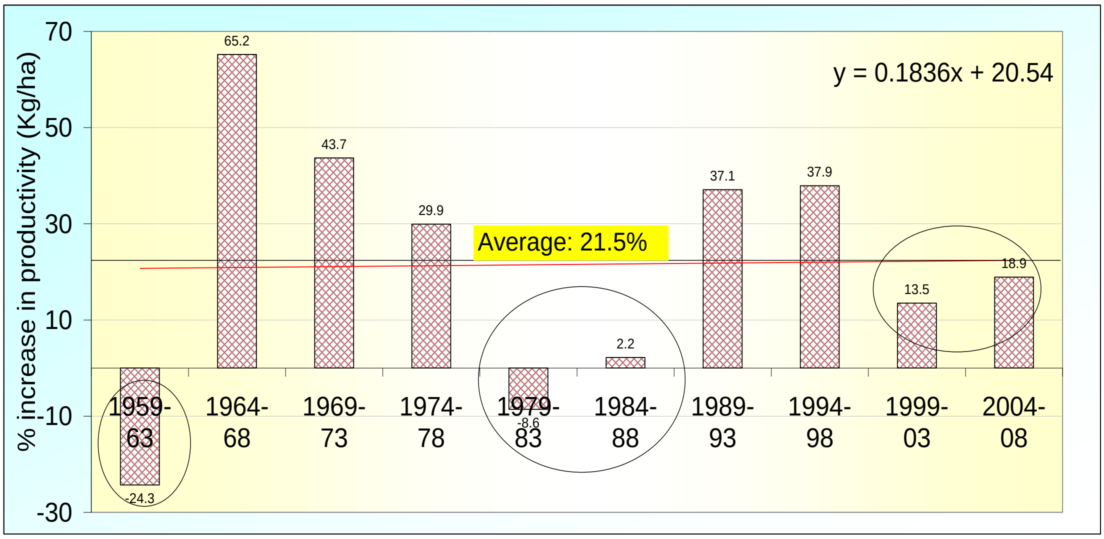


Fig.9.5 Pentad-wise rate of increase in rubber productivity in Kerala

The productivity of rubber showed a different pattern when the increase in productivity was considered on decade-wise. It was the lowest (6.7%) during 1981-90 followed by 31.7% in the recent decade 2001-09 (Fig.9.6). It is interesting tot note that the above pentads fell under these decades.

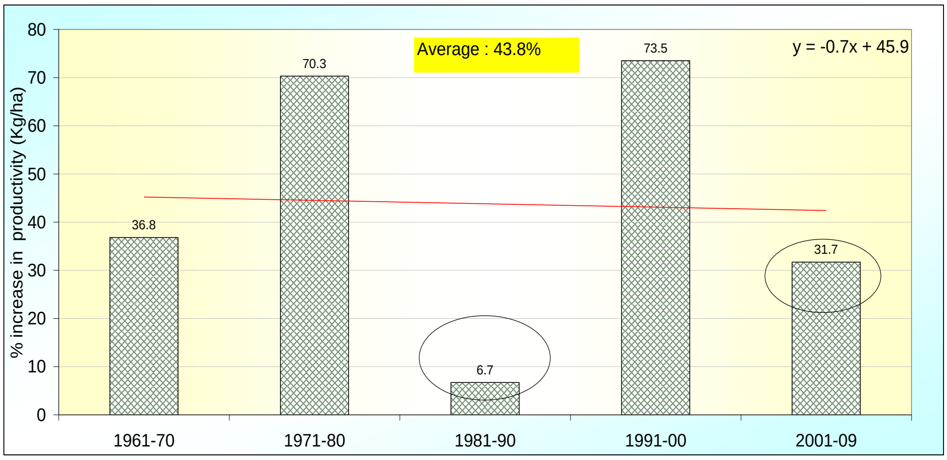


Fig.9.6 Decadal rate of increase in rubber productivity in Kerala

9.5 CLIMATE CHANGE IMPACTS ON RUBBER

Area, production and productivity of rubber have been increasing over a period of time. Rubber cultivating area since 1952-53 has increased by 727 per cent while it was 3960 per cent in the case of production. The increase in the case of productivity was 392 per cent. Tri-decadal area under rubber cultivation has registered an increase of 179 per cent while it was 589 per cent in the case of production. The increase was 155 per cent in the case of productivity *(See Figs.9.1& 9.2).* Overall, area, production and productivity of rubber have been increasing over the decades.

Despite increase in temperature, aridity index, number of droughts, decline in rainfall and moisture index (index of climate shifts), (Figs 9.7 & 9.8) the rubber productivity was in increasing trend. It indicated that the long term increase in temperature is unlikely to affect rubber yield adversely. At the same time, the prolonged dryspells during summer due to absence of rainfall during northeast monsoon and failure of summer showers is likely to affect rubber productivity adversely as seen in recent years. Abrupt changes in weather may affect the productivity of the crop as noticed in 2007-08, during which the yield declined (1471 Kg/ha) due to continuous rainfall and more number of rainy days when compared to that of previous year 2006-07 (1554 Kg/ha). Climate change in the form of climate variability, especially unpredictable, irregular and deficient rainfall pattern adversely affects the growth and productivity of natural rubber. Changes in rainfall pattern triggers fungal infection of leaves, which adversely affects productivity. The Country's production has declined to 8, 25,000 tonnes in 2007-08 from 8,52,000 tonnes in the previous year, according to official sources. Kerala, the main rubber growing state, witnessed about 30,000 tonnes fall in production at 7.53 lakh tonnes from previous year (The Business Standard, 3rd March, 2011). Heavy and extended rainfall with good number of rainy days hampered the tapping in rubber. Similarly, the yield in rubber is likely to be declined in 2010-11 due to the extended rains in post monsoon. Of course, soil erosion, soil degradation and insect, pest and diseases affect the yield of rubber which is again determined by the weather vagaries.

Rise in temperature may not have much role in determining rubber productivity as the thermal regime of rubber is not subjected to frequent fluctuations even during summer. It is rainfall- its quantum, distribution and number of rainy days which determine the yield decline in rubber. Rubber growing areas in south Kerala suffered due to heavy rainfall which extended up to December 2010. Good quality planting material having tolerance to drought and pest and disease attack are to be used extensively to combat the changes in weather in the contest of climate change and global warming to sustain rubber production in the country. In short, it revealed that rubber yield is not affected due to long term changes in temperature, but is likely to be affected due to short term monsoon uncertainties like prolonged rain during monsoon, followed by extended rain during post monsoon as seen in 2007 and 2010. Similarly, prolonged dryspells during summer may adversely affect rubber yield under rainfed conditions. Therefore, detailed studies in these directions are to be taken up with experimental data systematically collected for this purpose.

Fig.9.7 Decadal and tri-decadal trends in rainfall, aridity index, moisture index and number of droughts

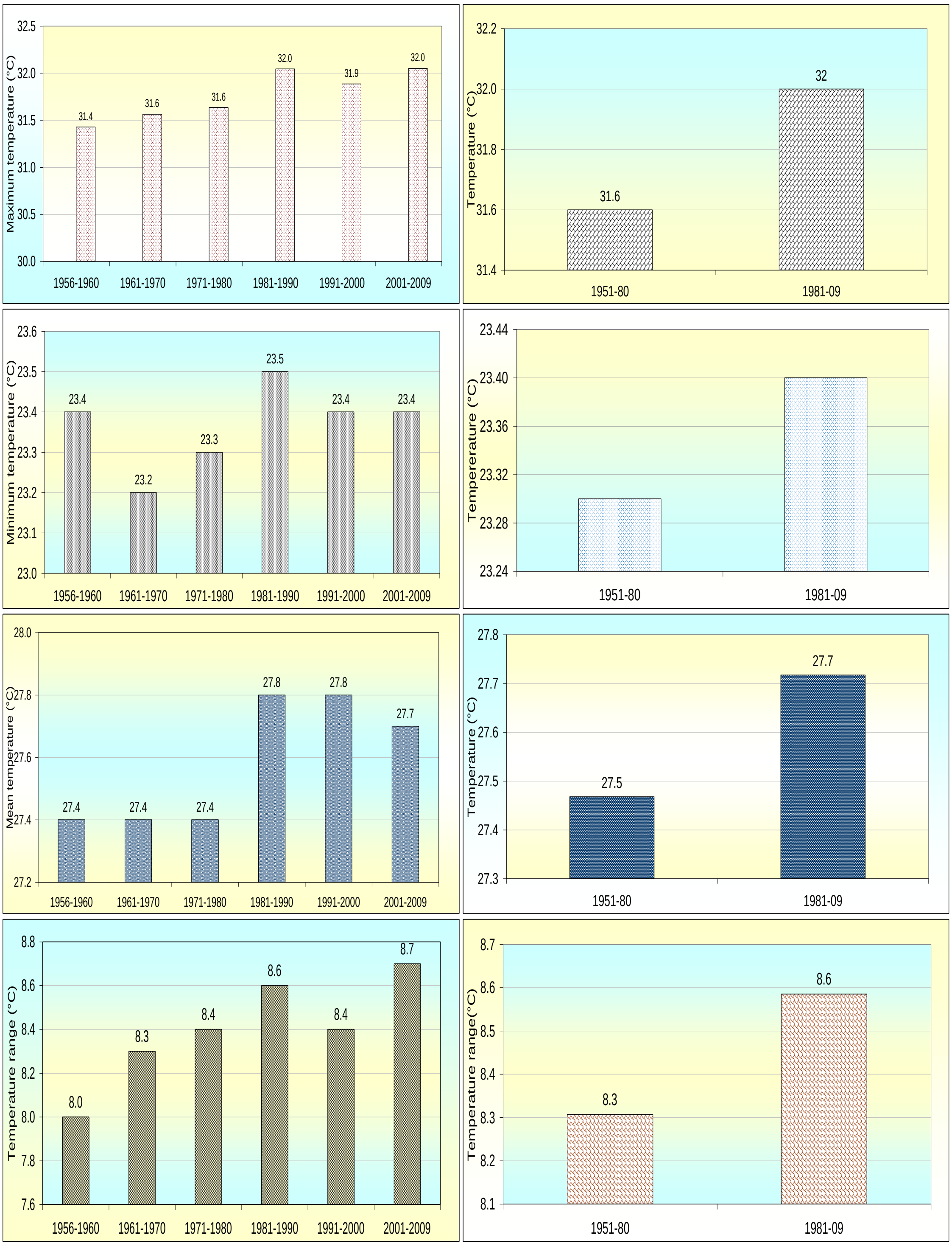


Fig.9. 8 Decadal and tri-decadal variations in temperature

Chapter 10

Summary and Conclusions

Kerala is situated in the southern tip of India between 8° 15' N and 12°50' N latitude and 74°50' E and 77°30' E longitude. It is popularly known as “Gods own country”. It is the “Gateway of monsoon” to the country as it is the entry point of monsoon to the Indian subcontinent. It is also one of the wettest places in the humid tropics. The annual rainfall of Kerala is about 2.7 times the national average, receiving about 3000 mm as against 1150 mm of the national average. The State is bestowed with 44 rivers and a number of backwaters, streams, canals and other inland water bodies and has rich biodiversity and the tropical rainforests spread in 13 agro-ecological zones. The Indian Ocean in the South, the Arabian Sea in the West, and the Western Ghats in the East surround the State. Due to the presence of North-South orientation of the Western Ghats, the State is blessed with copious rainfall during the southwest monsoon season (orographic effect). Though Kerala is identified as a plantation State, the major staple food is rice.

Though, more or less assured amount of rainfall is being received almost every year over the State, the inter-annual and intra-seasonal variability has been increasing in recent decades. Increasing uncertainties in rainfall are also being experienced as the State received deficit monsoon consecutively for more number of years during the current decade. Droughts during summer and floods during rainy season are not uncommon in Kerala. Weather related disasters like cloudbursts and landslides/mudslips are not uncommon across Kerala. Even sunburns were noticed in the border of

Thrissur and Palakkad districts in March 2010. The State's economy, to a great extent, is dependent on production of plantation crops, which is very much influenced by weather factors. Therefore, one of the objectives of the study was to update the knowledge on regional climate change/variability across the country. The study also aimed at understanding the climate change / variability zone - wise within the State of Kerala and to understand the vulnerable zones to climate change / variability. It also envisaged to understand the impact of climate variability / change on plantation crops and food security under the projected climate change scenario of Kerala. The results that emerged from the study are presented here:

The increase in annual mean temperature was 0.49°C over a period of 103 years (1901-2003. The increase in annual maximum temperature over the country was 0.76°C and 0.22°C in the case of minimum temperature resulting in an increase of 0.54°C in the annual temperature range. All the months showed warming trends though the trend in night temperature declined in half of the months (Jan, May, June, July, August and September). Increase in mean temperature was relatively high in post monsoon (0.0085°C per year), followed by winter (0.007°C per year) during 1901-2003. Among various zones in the country, increase in maximum (0.012°C per year), mean (0.0071°C per year) and range of temperature (0.0098°C per year) was relatively high across the West Coast of India when compared to that of other zones. It was not so in the case of minimum temperature as the Western Himalayas of India recorded a larger increase in minimum temperature when compared to that of other zones across the country.

The projected annual maximum temperature on tri-decadal basis from the base period of 1961-90 will be 0.9°C, 1.9°C and 2.8°C by 2020, 2050 and 2080 AD, respectively at the current rate of increase in India. It would be 0.7°C, 1.4°C and 2.1°C in the case of minimum temperature by 2020, 2050 and 2080 AD, respectively. The rate of increase in mean temperature is similar to that of minimum temperature (0.7°C, 1.4°C and 2.1°C, by 2020, 2050 and 2080 AD, respectively). Of course, the rate of increase in ensuing decades may vary depending upon the emission of greenhouse gases, in particular the emission of CO_2 as it accounts for about 70-75% of increase in atmospheric temperature.

The annual rainfall over the country showed a marginally increasing significant trend during the study period of 1813 to 2006. It was evident in 1871-1900 and 1931-60. An increasing trend in rainfall was noticed in all the seasons viz., southwest monsoon, post monsoon and winter except in summer during which there was a marginal decline in annual rainfall. At the same time, rainfall was increasing in recent decades during post monsoon season. The monthly rainfall also indicated a decline in June and an increase in July, August and September during the monsoon season, indicating a shift in rainfall in some zones.

On a regional scale, the maximum, minimum, mean temperatures and temperature ranges over Kerala showed an increasing trend during the study period from 1956 to 2009 and were significant since 1981 onwards. The increase in maximum temperature, minimum temperature, mean temperature and temperature range across the State was 0.72°C, 0.22°C, 0.48°C and 0.51°C, respectively over a period of 54 years.

The rise in maximum temperature was high (1.46°C) across the high ranges, followed by the coastal belt (1.09°C) of Kerala while the increase was relatively marginal (0.25°C) across the midlands. Therefore, the high ranges and coastal belt in Kerala are more vulnerable in terms of the rate of increase in temperature due to global warming. The added disadvantage for the coastal belt due to climate change was a possible rise in sea level.

At the current rate of tri-decadal increase in maximum temperature of 0.4°C during the study period, the increase in maximum temperature across Kerala is likely to be between 1.2°C and 1.6°C by 2051-80 and 2081-2100, respectively. It would be between 0.3°C and 0.4°C in the case of minimum temperature during the above periods. The increase in mean temperature is likely to be between 0.59°C and 0.76°C by 2051-80 and 2081-2100, respectively. In the case of temperature range, the increase is likely to be between 0.89°C and 1.14°C by 2051-80 and 2081-2100, respectively.

The trend in onset of monsoon revolves around 1st June +/- 7 days. It indicated that monsoon onset is likely to be before 1st June rather than after 1st June during the ensuing years.

A decline in monsoon rainfall and an increase in post monsoon rainfall were the trends obtained for the State of Kerala as a whole with the cyclic trends of 40-60 years. The contribution of southwest monsoon rainfall to the annual value is declining while the post monsoon contribution is increasing. It was also evident that rainfall during June and July is declining and that of

August and September is increasing within the monsoon period. The moisture index across the State of Kerala was moving from B4 to B3 humid, indicating that the State was moving from wetness to dryness within the humid climate. The intensity of summer droughts was also increasing across the State of Kerala though it falls under the heavy rainfall zone due to unimodal rainfall. The recent decades also witnessed more number of droughts.

The rate of increase in Indian foodgrains production was below the normal of 12.5% since last 15 years due to frequent occurrence of weather abnormalities like floods, droughts, heat and cold waves. While area and production of paddy was declining in Kerala, the productivity was increasing during the study period. The decline in paddy production varied between 2 to 17.6 per cent due to heavy rainfall. On an average, the effect of heavy rainfall on paddy production was 8.5 per cent. In the case of paddy productivity also, the effect of heavy rainfall during *kharif* varied between 2.2 and 14.9 per cent. Erratic behaviour of monsoon, extended post monsoon rainfall with intermittent dryspell during post monsoon and unusual summer rains are detrimental to paddy production in the State as noticed in recent years. Under the projected climate change scenario, the frequency of such instances is likely to be more and hence it is a threat to paddy production in the State.

The paddy productivity in Kerala is unlikely to decline due to long term climate change such as increase in temperature, but bound to decline to some extent through the abrupt short term changes as noticed in 2008, 2009 and 2010 in the form of monsoon uncertainties like long dry spell and floods. In fact, the paddy productivity can be increased further at the current rate of increase in temperature during *kharif* through better crop improvement and management techniques, for which R&D initiatives need to be taken up on priority basis as a part of food security under the projected climate change scenario.

High rainfall during the monsoon period, followed by a prolonged dry spell from November to May is detrimental to all the selected plantation crops under the study. However, cashew and black pepper perform relatively better under the prolonged dry spell conditions during the summer. In the case of black pepper, mortality rate was high in young pepper vines under prolonged dry spell/drought conditions during summer. Coffee and black pepper respond differently to summer rainfall because it is good in the case of coffee as it requires blossom and backing showers between February/March and March/April while it is not so in the case of black pepper as it needs dry spell. Therefore, in sub mountainous regions of Wayanad district, coffee and pepper are planted as a mixed farming system. That is why, when one crop (coffee) is benefited with good yield on receipt of summer showers, the other crop (black pepper) yield will be adversely affected. Therefore, farmers practice mixed farming of black pepper and coffee in order to get assured returns from unit cropped area. However, both the crops responded negatively to high annual rainfall.

The decline in cashew production was evident due to decline in cashew area since last two decades. A significant decline was also noticed in the case of cashew productivity. It can be attributed to various factors. However, the inter-annual variability in cashew yield could be explained due to weather aberrations like extended monsoon and increase in night temperature with less dew nights.

Increase in temperature, aridity and droughts with a simultaneous decline in rainfall and moisture index are the climate change indicators noticed in Kerala. Climate variability, in the form of extended monsoon rainfall with erratic distribution, dry spells in post monsoon, unusual summer showers and prolonged dry spells from November to May if pre-monsoon showers fail, adversely affect the crops in Kerala. It is a threat to agricultural production in the State of Kerala in the ensuing decades since the frequency of such weather extremes is likely to be more under projected climate change scenario. Therefore, there is a need for pro-active measures as a part of climate change adaptation for sustenance of agricultural production in the State of Kerala.

CONCLUSIONS AND RECOMMENDATIONS

The study revealed that southwest monsoon rainfall in Kerala has been declining while increasing in post monsoon season. The annual rainfall exhibits a cyclic trend of 40-60 years, with a significant decline in recent decades. The intensity of climatological droughts was increasing across the State of Kerala through it falls under heavy rainfall zone due to unimodal rainfall pattern. The moisture index across the State of Kerala was moving from B4 to B3 humid, indicating that the State was moving from wetness to dryness within the humid climate.

The study confirms that a warming Kerala is real as maximum, minimum and mean temperatures and temperature ranges are increasing. The rate of increase in maximum temperature was high (1.46°C) across the high ranges, followed by the coastal belt (1.09°C) of Kerala while the rate of increase was relatively marginal (0.25°C) across the midlands. The rate of increase in temperature across the high ranges is probably high because of deforestation. It indicates that the highranges and coastal belts in Kerala are vulnerable to global warming and climate change when compared to midlands.

Interestingly, the trend in annual rainfall is increasing at Pampadumpara (Idukki), while declining at Ambalavayal across the highranges. In the case of maximum temperature, it was showing increasing trend at Pampadumpara while declining trend at Ambalavayal. In the case of minimum temperature it is declining at Pampadumpara while increasing in Ambalavalal.

The paddy productivity in Kerala during *kharif* / *virippu* is unlikely to decline due to increasing temperature on the basis of long term climate change, but likely to decline to a considerable extent due to prolonged monsoon season, followed by unusual summer rains as noticed in 2007-08 and 2010-11.

All the plantation crops under study are vulnerable to climate variability such as floods and droughts rather than long term changes in temperature and rainfall.

Recommendations/suggestions for future line of work

- Network of meteorological observatories should be increased. Presently, the network of temperature stations under IMD across the State is scarce, though it has a good number of rain gauge stations. Hence, there is urgent need to record surface air temperature across the State. This will provide a better picture of temperature variability over the State under the projected climate change scenario. This still holds good across the highranges.
- Climate projections for smaller locations/regions are not available. Hence, there is a need to incorporate downscaling techniques in the GCM models for smaller geographical regions as well. It is true in the case of observational data.
- Crop species- specific and location- specific crop weather relationships are to be worked out based on long period experimental data.
- As crops are more vulnerable to short terms variabilities rather than long term climate changes, the impact of climate variability on crops has to be documented. Detailed investigations are the need of the hour to understand the short and long term effects of climate change in the case of plantation crops through crop-simulation models. To understand the impact of climate change on crops, simulation models need to be developed /revalidated.
- R & D initiatives are needed in climate change adaptation for sustenance of agricultural production in the State of Kerala.
- There is a need to train skilled personnel in the field of climate change adaptation and mitigation.

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