Proceedings of the WTO Workshop

Impact of climate change on the agricultural sector in tropical countries

LEAD PAPERS

Edited by

G.S.L.H.V. Prasada Rao
D. Alexander

Jointly organised by

WTO Cell, Department of Agriculture,
Govt. of Kerala

and

Kerala Agricultural University

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FOREWORD

Green economy and development play a vital role in minimizing the ill-effects of climate change in various sectors during the current century. It will be another global economy transformation like industrial revolution, technology revolution, followed by our modern era of globalization experienced during the last century for the development of world economy. Global warming and rainfall variability are likely to increase the occurrence of droughts and floods as well as heat and clod waves in addition to sea level rise due to melting of polar ice. The projected sea level rise may lead to disappearance of low lying areas of coastal belt in addition to damage to ocean biodiversity. They threaten seriously the livelihood of billions of people across the world. The year 1998 was the warmest year, followed by the year 2005. The global warming is due to huge emissions of greenhouse gases in which forests also play vital role. Deforestation is alarming over the world. In a tiny State like Kerala, the forest cover declined from 75% to 24%. Temperature rise and decline in rainfall since last sixty years were noticed over Kerala due to manmade interventions in terms of deforestation and wetlands decline. Occurrence of summer droughts and floods during monsoon season is not uncommon in recent decades over Kerala. As noticed over the world, Kerala too got heavy rains in 2005 and 2007. In contrast, the State also experienced severe drought during summer 1983 and 2004. The State's economy was badly hit during the above flood and drought years. 1987 was the warmest year over Kerala and the decade 1981-1990 experienced more number of droughts. The Western Ghats and the Northeast are two of the 25 hot spots of biodiversity in the World. Most of the biomes in India seem to be highly vulnerable to the projected change in climate in a relatively short span of 50 years. To highlight various issues on impact of climate change on Agriculture, the WTO Cell, Govt. of Kerala in collaboration with Kerala Agricultural University proposed to conduct one day workshop on 14th December, 2007 entitled "Impact of Climate Change on Agriculture in Tropical Countries" inviting guest lectures. I understand that four lead talks will be presented and discussed during the Workshop covering the sectors of Agriculture, Plantations and Fisheries with particular reference to Kerala. The delegates include farmers, officers from agricultural department, commodity boards, scientists from ICAR institutes and Agriculture University. It is also planned to release the publication covering the lead papers before commencement of Workshop. I hope the lectures will be deliberated in detail and pro-active measures chalked out against the natural disasters relevant to Kerala. On this occasion, I congratulate Dr. G.S.L.H.V. Prasada Rao and his team for their concerted efforts in organizing the Workshop in a befitting manner. I wish the deliberations of the Workshop a grand success.

Vellanikkara
12-12-2007

K. R. Viswambharan, IAS
Vice Chancellor

PREFACE

The WTO Cell, Department of Agriculture, Government of Kerala has sponsored a series of orientation lectures during 2007-08 on current issues like climate change, seed bill, retail marketing and genetic resources, in collaboration with the Kerala Agricultural University. As a part of this programme, one day workshop on "Impact of Climate Change on Agricultural Sectors in Tropical Countries" is organized at College of Fisheries, Kochi to highlight various issues in relation to climate change and its impact on Agriculture. Four lead papers will be presented at the Workshop covering agriculture, plantation crops and fisheries with reference to the humid tropical regions. Occurrence of floods and droughts, landslides, high and low surface air temperatures and rainfall decline in recent decades has become more frequent over Kerala. Unlike in seasonal crops, ill effects of weather abnormalities on plantation crops will be lasting long and the State's economy is adversely affected. Human-made interventions in terms of deforestation, life-styles, wetland decline in addition to the excess fossil fuel burning are likely to lead to global warming and rainfall decline at faster rate than expected in ensuing decades. Temperature increase and rainfall decline are already noticed over Kerala and it is a threat to the existing cropping systems across the highranges. Therefore, pro-active measures are the need of the hour through short-and-long term strategies for mitigating ill effects against weather related natural disasters. In this direction, there is an urgent need on awareness programme on climate change and its effects across the State to alert the climate linked society. Researchers need to document on quantitative impact of climate change/variability on various sectors for effective planning at the Government level to mitigate ill effects of weather abnormalities.

Current discussions ongoing at Bali (Indonesia) under UNFCCC on reduction of greenhouse gases as per the Kyoto Protocol Agreement may strengthen the green economics and development for fighting against climate change.

Proceedings of the lead papers are brought out in the form of publication. We are sure that it is of immense use to the climate linked society. On this occasion we profusely acknowledge the service rendered by Mr.C.S.Gopakumar, N.Krishnakumar and Mr.N.Manikandan, Department of Agrometeorology in bringing out this publication within a short notice of time.

We wish the proceedings of the Workshop a grand success.

Editors

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Impact of climate change on Agriculture

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Introduction

Increasing evidence over the past few decades indicate that significant changes in climate are taking place worldwide as a result of enhanced human activities. The inventions that were discovered during last few centuries, more so in the last century has altered the concentration of atmospheric constituents that lead to global warming. The major cause to climate change has been ascribed to the increased levels of greenhouse gases like carbon dioxide (CO_2), methane (CH_4), nitrous oxides (NO_2), chlorofluorocarbons (CFCs) beyond their natural levels due to the uncontrolled activities such as burning of fossil fuels, increased use of refrigerants and enhanced agricultural related practices. These activities accelerated the processes of climate change and increased the mean global temperatures by 0.6°C during the past 100 years, a phenomenon known as global warming. It has also induced increased climatic variability and occurrence of extreme weather events in many parts of the world. Studies indicate that the years *viz.*, 1997, 1998 and 1999 during the past century, recorded more warmer conditions across the globe, and the process continued in this decade also. Summer 2002 and 2003 were declared as warmest years on record by NOAA especially in the Asian sub continent and in Europe where the temperatures remained extremely high for long periods resulting in death of 20,000 human populations in Europe alone. Scientists attribute this to a long-term warming trend over the globe.

In large part of Asia, agricultural production is mainly dependent on the monsoonal rains. Evidences also indicate that large-scale climatic variations are prevalent at micro-regional level influencing the rainfall distribution in different parts of Asia. The causes of these regional climate changes vary from global to region level. It is evident that there was, there is and there will be climate variability at global, regional and local levels. Since climate is closely related to human activities and economic development including agricultural system, there is a serious concern about its stability (Sinha *et al.*, 2000). The awareness of the magnitude of the impact of climate change on society by the various governments led to adoption of an International Convention on Climate Change by United Nations in 1992. Article 2 of this convention called the UN Framework Convention on Climate Change (UNFCCC) makes two relevant stipulations relevant and important to agriculture, which is (a) prevent dangerous anthropogenic interference with the climatic system, and (b) to ensure that food production is not threatened. The two are related and need in-depth analysis.

The global climate system is a consequence of a link between the atmosphere, the oceans, the biosphere, the cryosphere, and the geosphere and any change to this system produced by forcing agents - results in climate change.

Some of the atmospheric constituents such as water vapour, carbon dioxide, methane, and nitrous oxide are transparent to short wave solar radiation and opaque to long wave radiation emitted by earths surface, thus, trapping the heat from sunlight near the Earth's surface known popularly as greenhouse effect. This effect keeps the planet 33°C warmer than it would otherwise be, allowing the earth to support life. With the advent of the industrial revolution, there has been a tremendous growth in the fossil-fuel utilization leading to increased carbon dioxide emissions over the globe especially since 1950s. In addition to this, the emission of chlorofluorocarbons (CFCs) and other chlorine and bromine compounds used in refrigeration and other industrial uses not only have an impact on the radiative forcing, but also have led to the depletion of the stratospheric ozone layer. Land-use change, due to urbanization and deforestation and agricultural practices, affect the physical and biological properties of the Earth's surface. Such effects also change the radiative forcing and have a potential impact on regional and global climate.

Global scenario of climate change

Weather observations indicated that the global average surface temperature has increased by 0.6°C (IPCC, 2001) since the 19th Century. The rate of warming is faster than at any other time, during the past 100 years, which is attributed to the increase in the proportion of carbon dioxide and other greenhouse gases in the atmosphere over the last century. Observations also indicated that all the warmest years during the past century across the globe occurred in the last two decades (1981-1990 and 1991-2000). Among these years, 1998 was the warmest year on record (IPCC, 2001). Increasing concentrations of greenhouse gases are likely to accelerate the rate of climate change. Model output estimates that the average global surface temperature could rise 0.6 to 2.5°C in the next fifty years, and 1.4 to 5.8°C in the next century, by doubling the concentrate of $C0_2$ with significant regional variation. The expected rise in temperature in higher latitudes will be much more than at equatorial regions. Also the increase in rainfall is not expected to be uniform.

Other than the changes in air temperature, global warming has potential impact on global precipitation patterns and the frequency of droughts and floods. Many researchers are of the opinion that an increase in temperature could lead to a more intensive use of water. The rates of evaporation from soils and water, as well as transpiration from plants, and the quantum of rainfall could increase. Climate models based solely on the effects of greenhouse gases predicted an increase in the amount of precipitation in the next 100 years.

Other impacts of global warming include mean sea level rise as a result of thermal expansion of the oceans and the melting of glaciers and polar ice sheets. The global mean sea level is projected to rise by 0.09 to 0.88 m over the next century. Due to global warming and sea level rise, many coastal systems can experience increased levels of inundation and storm flooding, accelerated coastal erosion, seawater intrusion into fresh groundwater and encroachment of tidal waters into estuaries and river systems. Climate change and global warming also affect the abundance, spawning, and availability of commercially important marine fisheries. Increase in sea surface temperature adversely affects coral and coral associated flora (sea grass, sea weed etc.) and fauna.

Global level projections on future changes in climate

Some of the global level projections on future changes in climate as given by IPCC Reports are as follows:

- For the next two decades, a warming of about 0.2°C per decade is projected for a range of IPCC Special Report on Emission Scenarios. Even if all the greenhouse gases are kept constant at the year 2000 levels, a warming of about 0.1°C per decade would be expected due to the slow response of the oceans.
- Continued greenhouse gas emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st Century.
- Different estimates of temperature change by the end of the Century (2090 – 2099) compared to the temperatures 1980 – 1999 ranged from 1.8 to 4.0°C under different greenhouse gas emission scenarios.
- Projected warming in 21st Century is expected to be greatest over the land and high over the northern latitudes and least over the southern ocean and parts of North Atlantic Ocean.
- It is very likely that heat waves and precipitation events will continue to come more frequent.
- Sea ice is projected to shrink in both Arctic and Antarctic under all greenhouse gas emission scenarios.
- Extra tropical storm tracks are projected to move pole-ward.

Current climate and its variability in India

- The monsoon rainfall at All India level does not show any trend and is random in nature over a long period of time.
- The presence of pockets of significant long-term changes in rainfall has been recorded.
- Areas of increasing trend in monsoon rainfall are found along the west coast, north Andhra Pradesh and north-west India and those of decreasing trend over east Madhya Pradesh and

adjoining areas, north-east India and parts of Gujarat and Kerala (-6 to -8% of normal over 100 years).

- Surface air temperature for the period 1901-2000 indicated a significant warming of 0.4°C for 100 years.
- The spatial distribution of temperature changes indicated a significant warming trend has been observed along the west coast, central India, and interior Peninsula and over northeast India. However, cooling trend has been observed in northwest and some parts in southern India.
- Instrumental records over the past 130 years do not show any significant long-term trend in the frequencies of large-scale droughts or floods in the summer monsoon season.
- The only change is the alternating sequence of multi-decadal periods of more frequent droughts followed by periods of less frequent droughts.
- The total frequency of cyclonic storms that form over Bay of Bengal has remained almost constant over the period 1887-1997. However, the frequency of severe cyclonic storms appears to have taken place in the recent decades.
- A slight decrease in trend in the frequency of cyclonic disturbances is apparent during the monsoon season.
- The model-simulated data shows a balance between simulated and observed extreme maximum temperatures in the peninsular regions. However, the model underestimates high temperature estimates in the mountainous regions of Kashmir, Sikkim, Arunachal Pradesh and overestimates by 5°C over northern place.

Projected climate change scenarios over India

The climate change scenarios for the Indian subcontinent as inferred by Lal *et al.* (2001) from simulation experiments using atmosphere-ocean GCMs under the four SRES marker scenarios are presented below. These results suggest an annual mean area-averaged surface warming over the Indian subcontinent to range between 3.5 and 5.5°C over the region by 2080s. These projections showed more warming in winter season over summer monsoon.

The spatial distribution of surface warming suggests a mean annual rise in surface temperatures in north India by 3°C or more by 2050. The study also suggests that during winter the surface mean air temperature could rise by 3°C in northern and central parts while it would rise by 2°C in southern parts by 2050. In case of rainfall, a marginal increase of 7 to 10 percent in annual rainfall is projected over the sub-continent by the year 2080. However, the study suggest a fall in rainfall by 5 to 25% in winter while it would be 10 to 15% increase in summer monsoon rainfall over the country. It was also reported that the date of onset of summer monsoon over India could become more variable in future.

Year	Season	Temperature change (°C)		Rainfall change (%)	
		Lowest	Highest	Lowest	Highest
2020s	Annual	1.00	1.41	2.16	5.97
	Rabi	1.08	1.54	-1.95	4.36
	Kharif	0.87	1.17	1.81	5.10
2050s	Annual	2.23	2.87	5.36	9.34
	Rabi	2.54	3.18	-9.22	3.82
	Kharif	1.81	2.37	7.18	10.52
2080s	Annual	3.53	5.55	7.38	9.90
	Rabi	4.14	6.31	-24.83	-4.50
	Kharif	2.91	4.62	10.10	15.18

(Source: Lal et al., 2001)

Potential impacts of climate change on agriculture

Agriculture is one sector, which is immediately affected by climate change, and it is expected that the impact on global agricultural production may be small. However, regional vulnerabilities to food deficits may increase. Short or long-term fluctuations in weather patterns - climate variability and climate change - can influence crop yields and can force farmers to adopt new agricultural practices in response to altered climatic conditions. Climate variability / change, therefore, has a direct impact on food security.

- The potential effect of climate change on agriculture is the shifts in the sowing time and length of growing seasons geographically, which would alter planting and harvesting dates of crops and varieties currently used in a particular area.

- In most tropical and sub-tropical regions potential yields are projected to decrease for most projected increases in temperature.
- In mid-latitudes, crop models indicate that warming of less than a few °C and the associated increase in CO_2 concentrations will lead to generally positive responses and generally negative responses with greater warming.
- In tropical agricultural areas, similar assessments indicate that yields of some crops would decrease with even minimal increases in temperature because they are near their maximum temperature tolerance (IPCC, 2001).
- The change in atmospheric concentration caused by the anthropogenic Greenhouse Gases (GHG) is observed to affect the plant metabolic activity and also the production directly.
- The effect of temperature rise will lead to an increase in biological activity as well as the physical and chemical processes. Increase in CO_2 concentration can lower pH, thereby, directly affecting both nutrient availability and microbial activity.
- The average atmospheric temperatures are expected to increase more near the poles than at the equator. As a result, the shift in climatic zones can be more pronounced in the higher latitudes. In mid-latitudes, the shift is expected in 200-300 km for every increase of 1°C (IUCC, 1992).
- Increased temperature resulting from global warming is likely to reduce the profit from wheat cultivation and will compel farmers of lower latitudes to opt for maize and sorghum which are better adopted to higher temperature.
- Morey and Sadaphal (1981) reported a decrease of wheat yield by 400 kg ha^{-1} for a unit increase of 1°C maximum temperature and 0.5 hr sunshine.

Climate change is also expected to increase both the evaporation and precipitation in some regions. However, if the rate of evaporation exceeds the rate of precipitation, soil becomes drier, lake levels will drop and rivers will carry less water. Warm water will likely increase Blue Green Algae and other unproductive algae that can reduce the levels of dissolved oxygen. As temperature increases many fishes try to look out for the cooler regions. Either they may try to move upstream of river or in to greater depths, which is not possible in smaller rivers and lakes. Researchers forecast substantial shift in fish habitats, disrupt pattern of aquatic plant and animal distribution, which may alter the fundamental ecosystem process and will result in major ecological change.

Some of the outputs from the crop growth models on climate change on crop growth and yield are as follows:

Direct effects on crop growth and yield

- Most of the simulation studies have shown a decrease in the duration and yield of crops as temperature increased in different parts of India.
- Yields of both *kharif* and *rabi* crops decreased as temperature increased; a 2°C increase resulted in 15-17 per cent decrease in the grain yield of both crops, but beyond that the decrease was very high in wheat.
- Since, there is greater probability of increase in temperature in *rabi*, it is likely that the productivity of wheat and other *rabi* crops would be significantly reduced.
- Wheat yields in central India are likely to suffer by up to 2 per cent in the pessimistic scenario but there is also a possibility that these might improve by 6 per cent if the global change is optimistic
- Sorghum, being a C_4 plant, does not show any significant response to increase in CO_2 and hence the different scenarios do not affect its yield.
- However, if the temperature increases are higher, western India may experience some negative effect on productivity due to reduced crop durations.
- The impact of warming scenarios becomes apparent at higher levels of fertilizer application from 2030 onwards.

- In future, therefore, much higher levels of fertilizer may need to be applied to meet the increasing demand for food.
- The production of fruits may be significantly affected if the changes in climate happen to coincide with the critical periods. Global warming will push the snow line higher and dense vegetation will shift upwards. This shift will be selective and species specific due to the differential response of plants to changing environmental conditions.
- The nutritional quality of cereals and pulses may also be moderately affected which, in turn, will have consequences for our nutritional security.
- The loss in farm-level net revenue may range between 9 per cent and 25 per cent for a temperature rise of 2-3.5°C.

Crop-pest interactions

- The change in climate may bring about changes in population dynamics, growth and distribution of insects and pests.
- Changes in rainfall, temperature and wind speed pattern may influence the migratory behaviour of the locust.
- Most crops have C_3 photosynthesis (responsive to CO_2), while many weeds are C_4 plants (non-responsive to CO_2). The climate change characterized by higher CO_2 concentration will favour crop growth over weeds.

Irrigation water availability

- Temperature increase associated with global warming will increase the rate of snow melting and consequently snow cover will decrease.
- In the short term, this may increase water flow in many rivers that, in turn, may lead to increased frequency of floods, especially in those systems where water carrying capacity has decreased due to sedimentation.
- In the long run, however, a receding snow line would result in reduced water flow in rivers.
- Under the climate change scenario, the onset of the summer monsoon over India is projected to be delayed and often uncertain.

- This will have a direct effect not only on the rainfed crops, but water storage will also be affected, placing stress on the irrigation water.
- Since the availability of water for agriculture would have to face tremendous competition for other uses of water, agriculture would come under greater strain in future.

Soil processes

- Changes in precipitation patterns and amount, and temperature can influence soil water content, run-off and erosion, workability, temperature, salinization, biodiversity, and organic carbon and nitrogen content.
- Changes in soil water induced by global climate change may affect all soil processes and ultimately, crop growth.
- An increase in temperature would also lead to increased evapotranspiration, which may result in the lowering of the groundwater table at some places.
- Increased temperature coupled with reduced rainfall may lead to upward water movement, leading to accumulation of salts in upper soil layers.
- A rise in sea level associated with increased temperature may lead to salt-water ingression in the coastal lands, making them unsuitable for conventional agriculture.
- An increase of 1°C in the soil temperature may lead to higher mineralization but N availability for crop growth may still decrease due to increased gaseous losses.

Implications of climate change on water availability

- The preliminary assessment has revealed that under the GHG scenario, the severity of droughts and intensity of floods in various parts of India is projected to increase.
- There is a general reduction in the quantity of the available run-off under the GHG scenario.
- Luni, the west flowing river of Kutchh and Saurastra occupying about one-fourths of the area of Gujarat and 60 per cent of the area of Rajasthan are likely to experience acute physical water scarce Conditions.

- The river basins of Mahi, Pennar, Sabarmati and Tapi are likely to experience constant water scarcities and shortage. The river basins of Cauvery, Ganga, Narmada and Krishna are likely to experience seasonal or regular water-stressed conditions.
- The river basins of the Godavari. Brahmani and Mahanadi are projected to experience water shortages only in a few locations.

Possible effects of climate change on groundwater

- It is apparent that the projected climate change leading to global warming, sea-level rise and melting of glaciers will disturb the water balance in different parts of India and quality of groundwater along the coastal track.
- Changes in precipitation and evapotranspiration may influence groundwater recharge
- Rising sea levels may lead to increased saline intrusion of coastal and island aquifers
- Increased rainfall intensity may lead to higher run-off and less recharge; and
- Increased flood events may affect groundwater quality in alluvial aquifers.

Socio-economic impacts due to shifts in major forest types

- Nearly 200,000 villages in India are situated in or on the fringe of forests.
- Further, about 200 million people depend on forests for their livelihood, directly or indirectly. Forest ecosystems in India are already subjected to socio-economic pressures leading to forest degradation and loss, with adverse impacts on the livelihoods of forest dependent communities.
- Climate change will be an additional pressure on forests, affecting biodiversity as well as biomass production. According to the assessment of projected climate impacts on forests, significant changes in the forest boundary of different forest biomes as well as biodiversity are projected.

- However, during the transient phase, large-scale forest dieback may occur. This may affect the production and supply of non-timber forest products to the forest dependent communities, affecting their livelihoods.
- In the transient phase, there could be an increased supply of timber, due to forest dieback, depreciating timber prices.

Climate-related coastal hazards - future scenario

- The past observations on the mean sea level along the Indian coast show a long-term rising trend of about 1.0 mm/year.
- However, the recent data suggests a rising trend of 2.5 mm/year in the sea level along Indian coastline.
- Model simulation studies, based on an ensemble of four AOGCM outputs, indicate that the oceanic region adjoining the Indian subcontinent is likely to warm at its surface by about 1.5-2.0°C by the middle of this century and by about 2.5-3.5°C by the end of the century.
- The corresponding thermal expansion, related sea-level rise is expected to be between 15 cm and 38cm by the middle of this century and between 46 cm and 59 cm by the end of the century.
- A one-meter sea level rise is projected to displace approximately 7.1 million people in India, and about 5,764 km^2 of land area will be lost, along with 4,200 km of roads.
- An increase in the frequency of severe cyclonic storms is likely under the climate change scenario; this may enhance the vulnerability of those districts that are already ranked as vulnerable under the current climate scenario.

Impacts on agriculture in different countries

India

- Simulations of the impact of climate change on wheat yields for several locations in India using a dynamic crop growth model, WTGROWS, indicated that productivity depended on the magnitude of temperature change. In north India, a 1°C rise in the mean temperature had no significant effect on potential yields though an increase of 2°C reduced potential grain yields at most places.

- Agriculture will be adversely affected not only by an increase or decrease in the overall amounts of rainfall, but also by shifts in the timing of rainfall. For instance, over the last few years, the Chhattisgarh region has received less than its share of pre-monsoon showers in May and June. These showers are important to ensure adequate moisture in fields being prepared for rice crops. Agriculture will be worst affected in the coastal regions of Gujarat and Maharashtra, where agriculturally fertile areas are vulnerable to inundation and salinization. Standing crop in these regions is also more likely to be damaged due to cyclonic activity.
- In Rajasthan, a 2°C rise in temperature was estimated to reduce production of pearl millet by 10-15 per cent (Ramakrishna *et al.*, 2002).
- The state of Madhya Pradesh, where soybean is grown on 77 per cent of all agricultural land, could dubiously benefit from an increase in carbon dioxide in the atmosphere. According to some studies, soybean yields could go up by as much as 50 per cent if the concentration of carbon dioxide in the atmosphere doubles.
- However, if this increase in carbon dioxide is accompanied by an increase in temperature, as expected, then soybean yields could actually decrease. If the maximum and minimum temperatures go up by 1°C and 1.5°C respectively, the gain in yield comes down to 35 per cent. If maximum and minimum temperatures rise by 3°C and 3.5°C respectively, then soybean yields will decrease by five per cent compared to 1998 (Lal, 1999).
- Changes in the soil, pests and weeds brought by climate change will also affect agriculture in India (TERI, 2002). For instance, the amount of moisture in the soil will be affected by changes in factors such as precipitation, runoff, and evaporation.

Africa

- Increased droughts could seriously reduce the amount of food available.

- Millet yields may decline by 63-79%.
- Yields of freshwater fish may increase, although the mix of fish species could be altered. While some fish species will fare better at increased temperatures, for example by increasing reproductive and feeding efficiency - other species are not as well adapted to higher temperatures, and their numbers are likely to decrease.
- Tsetse fly infestations could expand into more southerly areas of Zimbabwe and Mozambique, move westward in Angola, northeast in Tanzania. At the same time, their numbers may decrease in some of the areas where they currently exist.

Middle east and drier parts of Asia

- Wheat production in some areas may decline due to increased temperatures.
- There will probably be acute shortages of water.

Latin America

- Yield decreases are expected for several major crops in Mexico, Central America, Brazil, Chile, Argentina and Uruguay.
- Livestock production may decline due to water shortages in temperate grasslands.
- Extreme weather events such as floods and hurricanes may hurt livestock and crop production.

China and cooler parts of northern Asia

- Rice, wheat and maize yields will probably decline.
- Yields could increase in northern Siberia, and decrease in southern areas of Siberia.
- As water warms, aquaculture operations can shift to warm-water species, though diseases will have to be carefully managed.

Tropical Asia

- Rice, wheat and sorghum yields are expected to decline.

- Crop production will decrease by 12% overall in India, with several coastal areas being most negatively effected. Other areas are predicted to benefit to a small extent from warming.
- In some areas, for example in Pakistan, increased runoff in some river basins may cause more flooding and waterlogging, and increase the amount of salt in the soil.

Climate change and world food security

Climate change over the long-term, in particular global warming, could affect agriculture in a number of ways the majority of which would threaten food security for the world's most vulnerable people:

- The success rate of predictability of weather and climate would decrease, thus making planning of farm operations more difficult.
- Climate variability at regional scale might increase, putting additional stress on fragile farming systems.
- Weather extremes - which are very difficult to plan for - might become more frequent.
- The sea level would rise, threatening submergence of valuable coastal agricultural land, particularly in low-lying small islands.
- Biological diversity would be reduced in some of the world's most fragile environments, such as mangroves and tropical forests.
- Climatic and agro-ecological zones would shift, forcing farmers to adapt, as well as threatening natural vegetation and fauna.
- The imbalance of food production between cool and temperate climates tropical and subtropical regions could worsen.
- Distribution and quantities of fish and seafoods could change dramatically, wreaking havoc in established national fishery activities.
- Pests and vector-borne diseases would spread into new regions where they were previously not known.

Research thrusts

Several experts have identified research areas that would reduce uncertainty and improve knowledge to face the consequences of climate change and provide improved planning. The following are some of the points for consideration.

- Quantitative assessment of specific crop responses at different crop stages to enhanced levels of GHG, precipitation and UV-B radiation.
- Breeding agricultural crops for tolerance to high temperatures.
- New area that is made available for agriculture is to be properly categorized and mapped to avoid chances of in appropriate land-use choices.
- Probabilities of occurrence of extreme weather events (droughts & floods) and their impacts on plant growth.
- The impacts of elevated CO_2 on plant soil-water balances and the corresponding crop growth should be linked.
- Water balance for drought or flood prone regions in different parts of the world for changing climatic conditions.
- The quality of global modelling projections is further improved with suitable modifications in the global circulation models.
- The database for all the parameters need to be strengthened.

Suggested Readings

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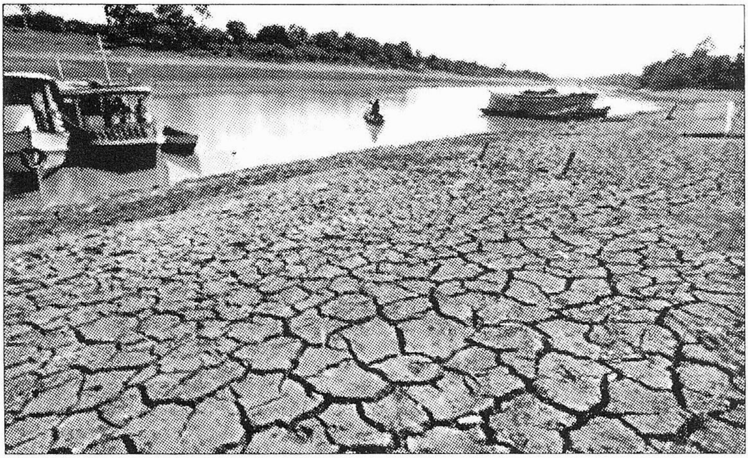

Climate change and plantations in the humid tropics

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Introduction

Climate change and variability are concerns of humankind. The recurrent drought and desertification threaten seriously the livelihood of over 1.2 billion people who depend on land for most of their needs. The global economy has adversely been influenced due to droughts and floods, cold and heat waves, forest fires, landslips and mudslips, icestorms, duststorms, hailstorms, thunder clouds associated with lightning and the sea level rise (Fig. 1). The year 1998 was the warmest and declared as the weather related

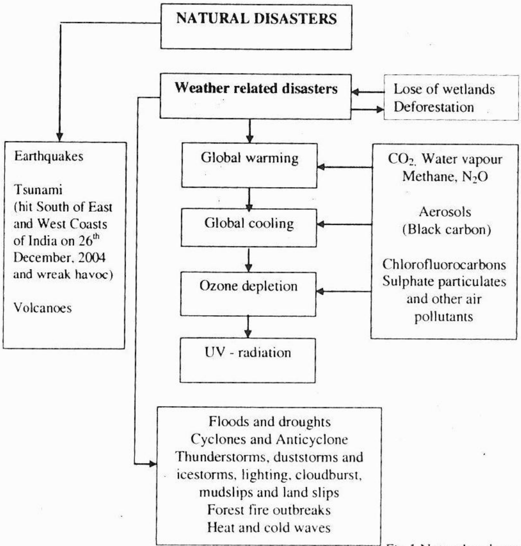

Fig. 1 Natural and weather related disasters

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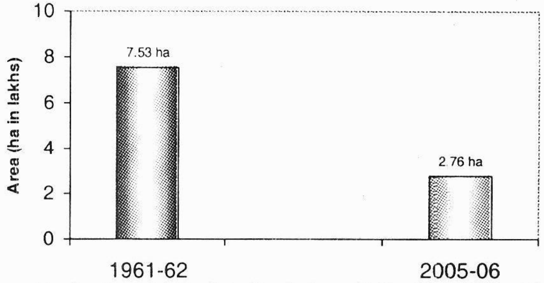
disaster year, which caused hurricane havoc in Central America and floods in China, India and Bangladesh. Canada and New England in the U.S suffered heavily due to icestorm in January while Turkey, Argentina and Paraguay with floods in June 1998. In contrast, huge crop losses were noticed in Maharashtra (India) due to unseasonal and poor distribution of rainfall during 1997-98. The 1997/1998 El Nino event, the strongest of the last century affected 110 million people and costed the global economy nearly US$ 100 billion. A string of 16 consecutive months saw record high global mean temperature in 1997-98. Statistics compiled from insurance companies for 1950-1999 showed that major natural catastrophes, which were weather related, caused estimated economic losses of US$960 billion. Most of the losses were recorded in recent years since 1995 onwards as the top ten warmest years occurred during the decade of 1995 - 2005.

The year 2005 was another historic second worst warmest year on record for hurricanes. The hurricane Katrina over new Orleans (USA) in August; the hurricane Rita in Texas, Central and Western Cuba and Southern Florida and typhoon over Hainan Province in South China and Vietnam during the last week of September, while early October over Mexican's Gulf coast; heavy downpour over Mumbai on 26th July, 2005 (Single-day the highest record rainfall of 944 mm) and 3rd September, 2005 over Bangalore; severe tropical storms in Andhra Pradesh in September; floods in Kerala, Karnataka, Maharashtra, Gujarat, Orissa and Himachal Pradesh during the Southwest monsoon (June-September), 2005 in India devastated cropped area to a large extent in addition to losses of thousands of human lives. In contrast, it was declared as a famine year in 24 sub-Sahara African countries due to drought and attack of locusts in 2005. Similarly, Australia experienced a severe drought in 2002 and heavy crop damage was noticed. Again in 2006, occurrence of droughts and floods devastated rice and other crops in Andhra Pradesh and 40% cereal production was affected in Karnataka due to drought. Similar was the case during monsoon 2007, causing floods across several continents (Hurricane Dean in August slammed into Mexico) including India and Bangladesh. Torrential downpour in June, 2007 over Kerala, Karnataka, Andhra Pradesh and that the foodgrain produ-ction is not in tune with plan estimates and the foodgrains production is likely to touch only a maximum of 260 million tonnes by 2020 at the present rate though it is projected as 400 million tonnes to declare India as one of the developed countries.



Decline in paddy lands in Kerala from 1961 - 62 to 2005 - 06

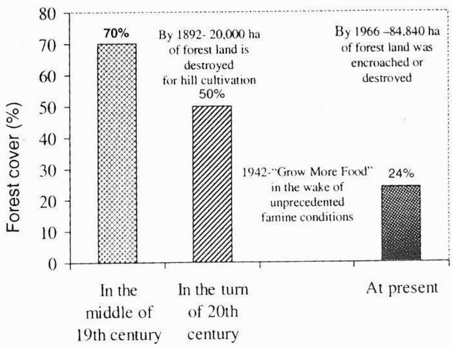
Increase in aerosols (atmospheric pollutants) due to emission of greenhouse gases including black carbon and chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs), Ozone depletion and UV-B filtered radiation, eruption of volcanoes, the "human hand" in deforestation in the form of forest fires and loss of wetlands in the process of imbalanced development are causal factors for climate variability and change. The loss of forest cover and wetlands, which normally intercept rainfall and allow it to be absorbed by the soil, causes precipitation to reach across the land, eroding top soil, causing floods and droughts. Paradoxically, the lack of trees also exacerbates drought in dry years by attaining soil to dry out more quickly.

Greenhouse effect

Carbon dioxide, water vapour, methane, carbon monoxide, sulphur and nitrous oxides, chlorofluorocarbons and chlorofluoromethanes are the atmospheric constituents of major importance. Incoming shortwave radiation is not absorbed by the above atmospheric constituents and the outgoing longwave radiation from the earth is absorbed by them and reradiate back to earth surface. In the process, earth warms up and its temperature raises. It is also known as the glasshouse effect as property of glass is that it allows solar radiation through it and disallows longwave radiation from earth, thereby warming takes place. The atmospheric constituents which have the property of absorbing longwave radiation and transparent to shortwave radiation are known as the greenhouse gases (GHG). Human activities like fossil fuel combustion, production of synthetic chemicals, biomass burning, deforestation, excess use of chemical fertilizers and pesticides change the chemical composition of atmosphere, thereby enhancing greenhouse effect. The frequent eruption of volcanoes in different parts of the globe in recent times is one of the predominant factors to change the chemical composition of atmosphere on which our knowledge is limited. The present growth rate of GHG is 1% in CH4, 0.4-0.5% in CO_2 and 0.2-0.3% in N_2O as per the Intergovernmental Panel on Climatic Change (IPCC, 2007). In addition to the above, chlorofluorocarbons and chlorofluoromethanes contribute significantly to greenhouse effect. Is the greenhouse effect mitigated by regional cooling effect from aerosols like black carbon? New research showed that the aerosol effect could dominate the greenhouse effect over the continents and by and large the effect of greenhouse will be slowed down. In contrast, the ozone - friendly substitutes for chlorofluorocarbons (CFCs) like hydrofluorocarbon (HFCs), hydrochlorofluoro-carbons (HCFCs) and perfluorocarbons (PFCs) are also powerful greenhouse gases that contribute to global warming. There is also evidence that faster rate of global warming since 1976 is human-induced.

Global warming

Global warming is the biggest long term threat to life on earth. Rise in temperature may drive thousands of species to extinction, trigger more frequent floods and droughts and sink low lying islands and coastal areas by rising sea levels. It is the result of rising atmospheric content of CO_2 mainly owing to burning of hydrocarbons or fossil fuels like as petrol and diesel. Destruction of forests and their degradation too contribute to rise in carbon dioxide levels. The IPCC (2006) projected the rate of warming



Forest cover over Kerala

for the 21st century to be between 0.8 and 4.4 °C at various stabilized CO_2 levels in atmosphere and it is most likely to be 3°C by end of this century. It could cost global economy almost $7 trillion by 2050, is equivalent to a 20 % fall in growth if no action is taken on greenhouse gas emissions (Fig. 3). If action is taken, it will cost only $350 billion due to climate change already taken place, just 1% of the global GDP. The winter 2007 was the warmest and recorded 0.85 °C above average of 12 °C and the previous highest was 0.71 °C, which occurred in 2002 in Northern Hemisphere. The entire Europe Union recorded the warm winter, having more than 2 °C above average. New York experienced the highest temperature of 21.7 °C on a day in January, 2007 and the second highest was recorded as 17.2 °C in 1950. As predicted, whether the year 2007 could overtake 1998 to become the warmest year on record? However, floods and excess rains were also noticed due to hurricanes and tropical storms worldwide in 2007.

The increase in all-India mean temperatures is almost solely contributed by increase in maximum temperature (0.6°C/100years)

Economics of climate change: It could cost the global economy almost $7trillion by 2050-equal to a 20 per cent fall in growth – if no action is taken on greenhouse gas emissions. Taking action now could cost just one per cent - $350billion – of global GDP (Source: Stern report, IPCC, DoE, 2006)

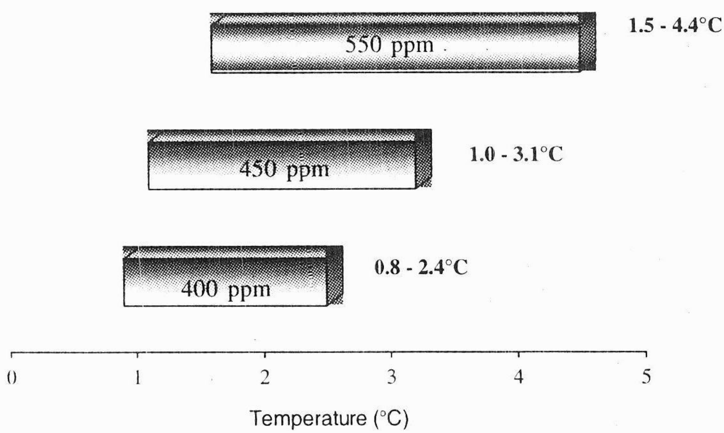
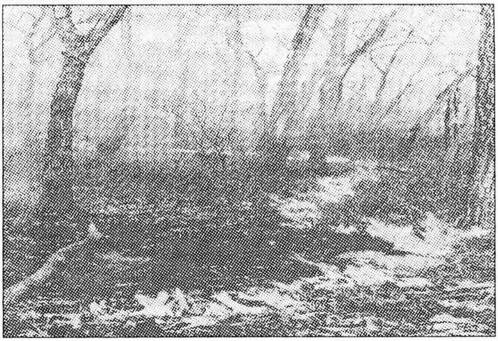


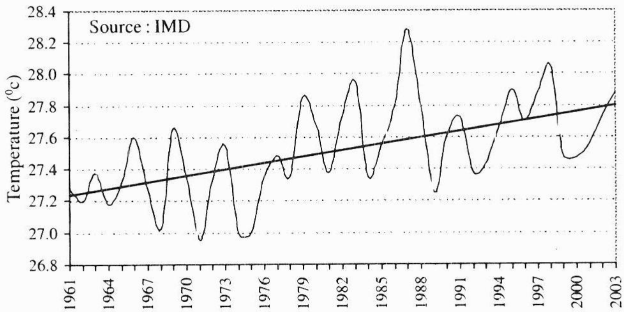
Fig. 3 Projected CO_2 versus Temperature rise and its economics

with minimum temperature remaining practically trendless. Consequently, there is a general increase in diurnal range of temperature. In rainfall, there was a decrease since last 50 years. 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 end of the Century. It is more pronounced over northern parts of India. The mean sea level rise is likely to be slightly less than 1mm/ year along the Indian coast. Greater number of high surges and increased occurrences of cyclones in post-monsoon period along with increased maximum wind speed are also expected as per Ministry of Environment and Forests (MoEF), Govt. of India and Department of Environment, Food and Rural Affairs (DEFRA), U.K. This phenomenon of climate change threatens the area of land availability for farming. As per the United Nations Report of FAO, India stands to lose 125 million tonnes, equivalent to 18% of its rainfed cereal production from climate change by 2015. China's rainfed cereal production potential of 360 million tones is expected to increase by 15% during the same period. It would also cause a worldwide drop in cereal crops between 20 and 400 million tonnes, put 400 million more people at risk of hunger, and put up to three billion people at risk of flooding and without



Forest fires - The all – engulfing blaze

To fetch a pot of water from a well miles away during summer (Chittur Taluk in Palakkad district) access to fresh water supplies. The crop production losses due to climate change may also drastically increase number of undernourished people, severely hindering progress in combating poverty and food security. The severest impact is likely to be in sub-Saharan African countries, which are the least able to adapt climate change or to compensate for it through increase in food imports. In 2004 and 2005, 24 sub-Saharan African countries faced food emergencies, caused by a lethal combination of locusts and drought. In addition, adverse hot and dry weather in United States and drought conditions in parts of the European Union lowered cereal output during 2005 when compared to that of 2004. The simulation models indicate that the global warming leads to reduction in rice and wheat production in North India.



Trend in mean surface air temperature over Kerala from 1961 to 2003

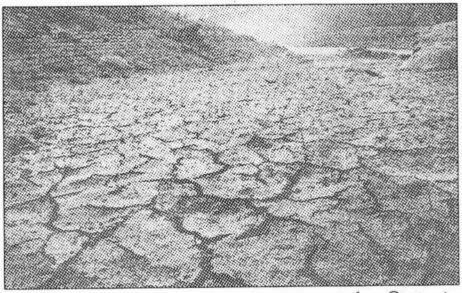
Atmospheric carbon dioxide (CO_2)

CO_2 being an efficient absorber of long wave radiation from earth, it is of great climatic significance. Carbon dioxide has important absorption peaks at about 2, 3 and 4μ and a major absorption peak at about 15μ. This gas emits half of the absorbed heat back to earth, influencing flow of energy between earth and atmosphere. CO_2 is a very important atmospheric constituent in the heat budget of earth and atmosphere. There is a sharp increase in carbon dioxide in recent decades due to human-made interventions in terms of burning fossil fuels like coal, oil and natural gases. The projected concentration of CO_2 in the atmosphere by 2050 is as follows:

Projected concentration of CO_2 in the atmosphere

Period	CO_2 *concentration*
Before pre-industrial revolution	250-290 ppm
1958	315 ppm
1984	354 ppm
2005	379 ppm
Projection by 2050	>450 ppm

The concentration of carbon dioxide in atmosphere was in a steady state at 280 ppm till the pre - industrial period, 1950. It is rising since then at the rate of 1.5 to 1.8 ppm/ year. The concentration of carbon dioxide in atmosphere increased from 280 before 1950 to 370 ppm in 2000. It is likely to be doubled by the end of 21st century if preventive steps are not taken. Measurements at IARI, New Delhi showed that the concentration of carbon dioxide increased from 330 to more than 370 ppm, indicating similar trend of global phenomena. Over the same period, atmospheric concentrations of methane and nitrous oxide increased by 151 and 17%, respectively. This resulted in an increase of global temperature by 0.6 °C, causing global warming. As a result of warming, the global mean sea level rose by between 10 and 20 cm. The rise is as much as 10 times the average increase in the last 3000 years. An increase of 2.5mm/year is noticed in sea level of the Indian Ocean since 1950s. The trend appears to be higher on the East Coast when compared to that of the West Coast. It is likely that the rate and duration of warming of 20th century were larger than at any other time during the last 1000 years.



Water level in the reservoirs across the State is depleting fast – parched earth on the Chimmini dam site in Thrissur district in March 2004 (drought year)

In temperate soils, unexpected loss of carbon is taking place due to global warming. It leads to more carbon dioxide in the atmosphere, which means even more global warming. The findings showed that the carbon was being lost from soil at an average of 0.6% a year and richer the soils, higher the rate of carbon loss. There was no single factor other than global warming that could explain such losses in non-agricultural soils.

Aerosols and global cooling

Climate change is usually associated with increasing levels of greenhouse gases, a large amount of soot and other pollutants into the atmosphere in the form of tiny particles, known as aerosols. Aerosols can, however, be produced naturally too. There is great variation in the amount of aerosols around the globe and are unevenly distributed. They change from time to time depending on type of aerosols and quantities in which they are present. Many aerosols are invisible to naked eye and are microscopic. They include sea salts from breaking sea waves, pollen, fine seeds of plants, spores, bacteria and various organisms lifted by wind, smoke and black carbon (soot) from fires, tiny sand particles, volcanic ashes and meteoric dust. Likewise, sulphur-containing compounds known as sulphates arise by natural processes and plants release organic materials. Aerosols in the process of scattering, contribute to varied colours of red and orange at sunset and sunrise. Blue of the sky is also due to selective scattering by microscopic dust particles.

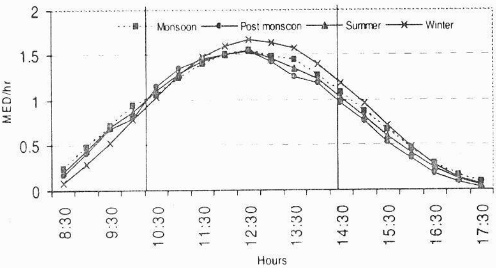
From global warming point of view, these tiny soot particles are very important. They absorb a part of incoming shortwave solar energy, thereby heating up the lower atmosphere and totally burning off clouds that might have formed. The combined effect of increasing greenhouse gases and human-induced soot in the warming of lower atmosphere could be as much as 0.25 degrees Celsius/ decade (positive effect). Aerosols are tiny particles, of about one micron, which scatter sunlight back to space and then cause a regional cooling effect (negative effect). Such aerosols are sulphates, soot, organic carbon and mineral dust. Black carbon absorbs solar radiation in visible spectrum and reduces amount of radiation reaching earth surface. Increase in black carbon alters large scale atmospheric circulation and hydrological cycle. Black carbon is a product of incomplete combustion of coal, diesel fuels, biofuels and outdoor biomass burning generated from industrial pollution, traffic, outdoor fires and household burning of coal and biomass fuels. The imbalance between positive (warming effect) and negative (cooling effect) aerosol forcing may slow down sometimes the global warming or may lead to global cooling. As the life span of human induced aerosols in the atmosphere is short- lived (one to three weeks) while the long-lived greenhouse gases may persist and thereby accumulate, leading to overall global warming. Many models indicate that global warming would increase rainfall over India while decrease in rainfall was noticed when the effect of aerosols was introduced. The gradual decrease in rainfall over India since last fifty years supports the theory of effect of aerosols on decline in rainfall. If that is the case, frequency of droughts in India could increase in coming decades if pollution continued unabated.

Clouds and global warming/cooling

Hygroscopic aerosols act as nuclei for cloud formation. Clouds would not form if there are no fine particles in the atmosphere around which water vapour could condense into droplets. Brown clouds contain a variety of aerosols, including sulphates from coal combustion, nitrates produced by vehicular emissions, and soot resulting from fossil fuel combustion and the burning of biomasses. They enhance warming quite a bit in lower atmosphere. Clouds play a dual role in cooling and warming of earth. If the sky is totally covered with clouds, clouds act as an active surface instead of earth surface. The incoming solar radiation is reflected back to a large extent from top of clouds and thus low solar radiation reaches earth surface. This keeps the planet cool. On the other hand, they absorb long wave radiation and emit back in all directions and transmit little long wave radiation to space. In the process, atmosphere traps huge amounts of heat emitted from earth's surface and clouds, leading to green house effect. Clouds are known as warm clouds in the tropics while cold clouds in temperate zones. Clouds over the oceans differ in character and heating effects to that of clouds over the continents. Their nature and effects also vary with season and time of day. Tropical clouds trap three times as much heat as clouds trap on a global average, but also reflect so much sunlight that the heating effect is cancelled out. Since the tropics account for 20% of earth's surface and effects of tropical cumulonimbus clouds are disproportionate, the delicate heat balance they maintain is critical. A warmer ocean would likely to cause more clouds to form, increasing both their heating and cooling effect. Analysis of satellite data also showed that the clouds like stratocumulus over temperate regions reflect enough sunlight to exert a net cooling effect locally, and this appears to account for clouds overall cooling effect worldwide. The behaviour of disproportionate cooling and heating may change itself under global warming, perhaps. If it is understood, climatologists may be able to forecast the timing and extent of expected global warming with far more confidence than today.

Ozone depletion and UV radiation

The greatest concentration of ozone is at an average in height of 25 km and above in the stratosphere. The ozone molecule is made up of three atoms of oxygen. It is the most efficient absorber of ultraviolet radiation from sun and thus protects all life forms in planet earth. Ozone depletion due to industrialization in recent decades is the concern of humankind and biological activities. Release of compounds like chlorofluorocarbons (CFCs), carbon tetrachloride and methyl chloroform could significantly deplete ozone layer that shielded the planet from ultraviolet radiation. The CFCs are used in a variety of industrial, commercial, and household applications. These substances are non-toxic, non-flammable and non-reactive. They are used as coolants in commercial and home refrigeration units, aerosol profellants and electronic cleaning solvents.



Diurnal profile of UV-B radiation in different seasons at Vellanikkara from 2002 to 2005

The global average thickness of ozone is 300 Dibson units, equivalent to 3mm. In contrast, it is about 100 Dibson units, which alarm us that we are in great danger if precautionary steps are not taken up. The ozone level fell to 90 Dibson Units, which was the lowest value recorded on 30-09-98 nearly equalled to the lowest value ever recorded 88 Dobson Units on 28-09-94 over Antarctica. The ozone losses are caused by chlorine and bromine compounds released by chlorofluorocarbons and halons. Year-to-year variation of size and depth of ozone hole depend on variations in meteorological conditions. The unusual cold temperature by 5-9 °F over Antarctic zone enables greater activation of reactive chlorine that ultimately causes more ozone loss and lower ozone levels. Increase in chlorine levels should peak in the Antarctic stratosphere within a few years (Shashi et al., 2002).

Among UV radiations, UV-B radiation in the range of 280-320 ηm is more sensitive to ozone fluctuations and reaches earth surface. A global network is created to monitor UV-B filtered radiation in terms of Minimum Erythema Dose (MED). The human-made interventions in industrial development lead to ozone depletion, thereby filtered UV radiation reaches the ground, resulting in various human, animal and crop diseases. The ozone loss has the potential to increase incidence of skin cancer, cataracts and damage to people's immune system, harm some crops and interfere with marine life. However, little is known on impact of ozone depletion and increasing UV-B radiation on ontogeny of tropical plants and human and animal diseases since studies in this direction are lacking. Because CFCs remain in the atmosphere for100 years, continued accumulation of these chemicals pose ongoing threats, even after their use is discontinued.

Models on global warming indicate that the rise in temperature is likely to be around 3 ° C by end of this century. It is likely that the extreme weather events like droughts and floods, cold and heat waves increase in coming decades. The human and crop losses are likely to be heavy. The global economy will be adversely affected as mentioned in the latest report of IPCC. If sea level increases as projected, the coastal areas which are thickly populated will be in peril and for the existing population, the safe drinking water will be a great problem. The whole climate change is associated with increasing greenhouse gases and human- induced aerosols and the imbalance between them may lead to uncertainty even in year-to-year monsoon behaviour over India. Therefore, there should be a determined effort from developed and developing countries to make industrialisation environment-friendly by reducing greenhouse gases pumping into atmosphere. In the same fashion, awareness programmes on climate change and its effects in various sectors viz., agriculture, health, infrastructure, water, forestry, biodiversity and sea level and the role played by human beings in climate change need to be taken up on priority. In the process, life style of people should be changed so as not to harm Earth-Atmosphere continuum by pumping CFCs into atmosphere. From the agriculture point of view, effects of extreme weather events on crops are to be documented so that it will be handy to planners in such reoccurrence events for mitigating the ill effects. Also, there is need to guide planners on projected future crop scenarios based on climate change events, which will be more realistic at field level as models always overestimate the impacts. Finally, we have to foresee these extreme events and prepare ahead to combat them so that the losses can be minimised.

Climate and plantations

Climate plays a major role in crop distribution while weather in crop productivity. Climate decides the crop habitat while crop habit depends on genotype and phenotype. By genotype it is meant the heredity received by the organism, which is relatively constant throughout life. Phenotype refers to the appearance of the organism- what it looks like- which is subject to change throughout life (Johannsen, 1903). The crop phenology like flushing, flowering, fruit development and harvest time are sensitive to vagaries in weather and differs from crop to crop. The phenological events undergo several abiotic and biotic stresses or environmental stresses as seen in the case of cashew flowering (Fig. 4) during the process of crop growth and development. The effect of environmental stress on phenology could adversely affect final yield in the same year or the following years depending upon type of crop in the case of plantation crops. Of course, a majority of plantation crops show seasonal behaviour in phenological events though they are perennial except

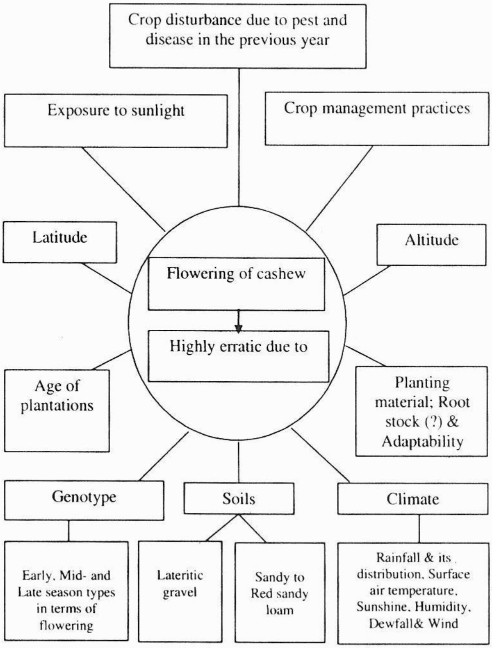


Fig. 4 Effect of abiotic and biotic factors on flowering of cashew

crops like coconut, having flowering phase round-the-year. The habitat of plantation crops is different as they are perennials traditionally grown in the humid tropics under the rainfed conditions. Within the tropics, crops like coffee, cardamom and tea prefer cool-temperate climate as they grow along the high ranges, where mean annual temperature varies between 14 and 20°C while coconut, cashew, cocoa and rubber are seen cultivated in mid - and - high lands, where the annual mean temperature revolves between 25 and 29°C. Interestingly, black pepper is in the buffer zone as an intercrop between warm and cool climates, stretching between tropical and temperate climates within the tropics due to its adaptability. According to thermal regime, black pepper is grown under "Meso therms and Micro therms-I and II" while cardamom, coffee (arabica) and tea under "Micro therms III". Black pepper likes moderate and low surface air temperature to some extent while cardamom low temperature only round-the-year, thus indicating different habitat under which they grow in rainfed conditions.

Similarly, the flowering behaviour in fruit crops is influenced by geographical coordinates like latitude, longitude and altitude as per the Hopkins' Bioclimatic law (1938), which states that a biotic event in North America will, in general, show "a lag of four days for each

Thermal regime and plantation crops distribution across the Western Ghats of Kerala

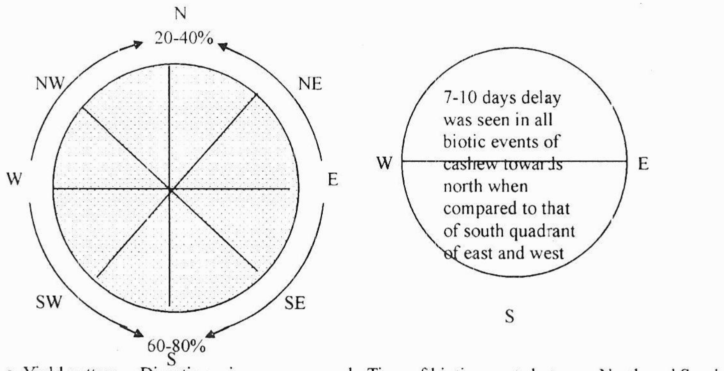
Class	Region	Temperature conditions	Altitude above MSL	Crops
Mega therms	Low land	High to moderate temperature throughout the year	0-10 m	Coconut, arecanut and cashew
Meso therms	Mid land	Moderate temperature throughout the year, winter temperature is relatively low	10-100 m	Coconut,cocoa arecanut, rubber,cashew and black pepper
Micro therms – II	High land	Moderate to low temperature throughout the year, winter temperature is low	100-500 m	Rubber, coconut,cashew, arecanut and black pepper
Micro therms - III	High land	Low temperature throughout the year, winter temperature is low	500-1000 m	Coffee (robusta), rubber, arecanut and black pepper
	High ranges	Low temperature throughout the year, winter temperature occasionally goes below 0° C.	1000-2500 m	Tea, coffee (arabica) and cardamom

degree of latitude, five degree of longitude and four hundred feet of altitude, northward, eastward and upward in spring and early summer". In mango, the India Meteorological Department also established that there is a delay in flowering from South to North of India, which generally followed Hopkins' Bioclimatic Law (IMD, 1957).Similar results were obtained in flowering of cashew.

Climate and cashew

The cashew growing regions across the World are located commercially between 15°N and 15°S from the equator. In India, it is grown along the East and West Coasts and regarded as a coastal tree since confining the coastal area never exceeds 300 m contour line. Though it is known as a coastal tree, it is seen cultivated at higher altitudes too. The altitude of the region where cashew can be grown depends on latitude of the place. For example, cashew in Tanzania and Brazil is grown up to 1000m AMSL whereas in Assam (India) cashew is not suitable for altitudes 170 m AMSL. Cashew productivity is poor in inland plateau and at higher altitudes depending upon distribution of rainfall and temperature as it prefers only coastal climates. Cashew shows a tendency for late flowering and fruiting irrespective of latitude depending upon the altitude. Being a tropical crop, cashew has the ability to thrive in high temperatures. In its natural habitat, it extends into the semiarid regions like northern Mosambique where daily maximum temperatures exceed 40°C. It is similar in the East Coast of India also, where cashew is grown. It appears that cashew responds to phototropism as it produces better under sunlight. A delay of one week to 10 days in all biotic events of cashew like bud break and flowering may also be noticed towards north direction within a cashew tree (Fig.5) Cashew is not only photosensitive and thermo-sensitive as the biotic events respond to low minimum and high maximum surface air temperatures. It seems that a temperature range between l5 and 35°C may be the optimum for better growth and production of cashew. The surface air temperature is conducive across the West coast for better cashew yield while it may not be so across the East Coast under rainfed conditions.

A cashew plant, undergoes first a dry spell and waits for the second dry spell to occur for break of bud. It appears that both the



a. Yield pattern – Direction wise b. Time of biotic events between North and South

Fig. 5 Directional influence on biotic events and yield pattern of cashew

dry spells at the time of bud break and thirty days prior to bud break with bright sunshine are critical as far as the cashew bud break is concerned. Influence of dry spell and bright sunshine in the mechanism of bud break of cashew are yet to be understood. The soil moisture stress has no relevance as the bud break of cashew begins much earlier before soil moisture stress starts. Instead, flowering of cashew requires relatively dry atmosphere with mild winter for better flowering. The mild winter may be defined as "Low minimum surface air temperature ranging between 15 and 20°C coupled with more dew nights having moderate dew". The continuous rains without critical dry spell may delay bud break of cashew. The unusual rains during November and December may lead to delay in reproductive phase of cashew along the West Coast (Fig.6), missing the mild winter and thus yields low. Cashew is enamoured

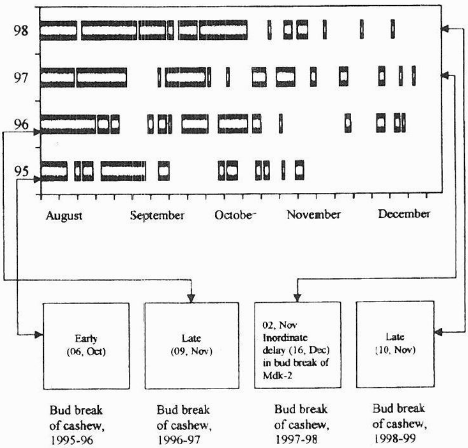


Fig.6 Daily rainfall distribution during August-December from 1995 to 1998 at RARS, Pilicode

with dry spell/drought during its reproductive phase and provides relatively better yield as it is seen grown under uni-model distribution of rainfall (Fig.7), having 650 to 3600 mm rainfall spread in 45 to 120 days. The abnormal drought situation affects the quality of cashew nuts very much under rainfed conditions. The delay in crop duration could be explained with geographical co-ordinates once the bud break in cashew is initiated immediately after the rain spell is over. The law stated by Hopkins (1938) holds good in all biotic events of cashew under better crop management in rainfed situations of tropical monsoon climates, provided the genotype and rainfall distribution are uniform. 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 the humid tropical monsoon climates, there is a delay of six days in cashew flowering at every 1° of North latitude and for every 100 meters of altitu-de, the delay in cashew flowe-ring is three days (Fig.8).

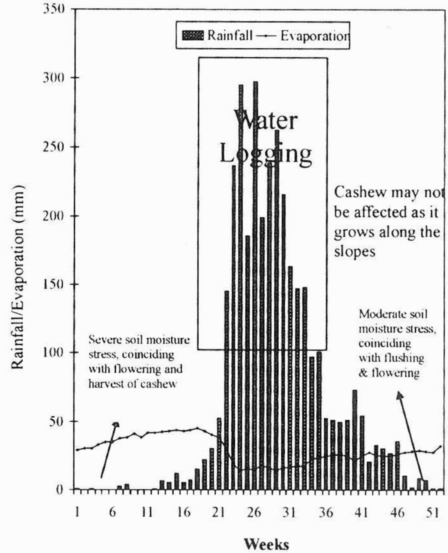


Fig 7. Mean weekly rainfall versus evaporation at RARS, Pilicode

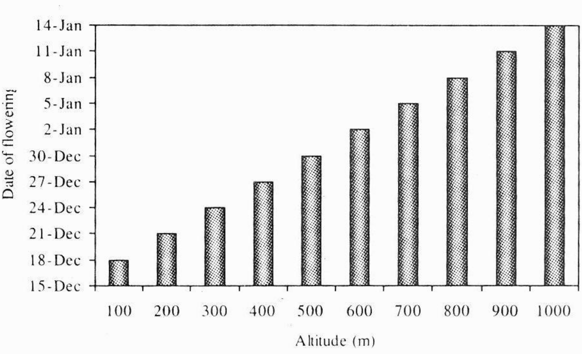


Fig.8 .Influence of altitude on cashew flowering

The kernel weight depends on availability of soil moisture, important during nut setting and development. It is one of the reasons why weight of cashew nuts is relatively more if a good shower is noticed during nut development phase. The shelling (%) also is high under above conditions. The nut and kernel weights may be better with altitude in early season types though the shelling (%) is less. It may not be the case with late season types. Depending upon genotype and its adaptability, the nut and kernel weights are superior in both West and East Coasts of India. The shelling (%) is low across the East Coast when compared to that of the West Coast. This could be explained due to high maximum temperature (35-40°C), which reduces nut development phase of cashew. The day maximum temperature shoots up to 42°C during nut development phase of cashew across the East coast while not so in West Coast and hence the nut size is adversely affected along the East Coast under rainfed conditions. It could be some extent manipulated through summer irrigation. The cashew yield and kernel weight are influenced by number of heat units if other meteorological factors are not in hindrance with nut development and yield. The early varieties need less number of heat units while more in case of late varieties of cashew. The nut characters also respond to phototropism also. Further studies are needed in this direction.

Night temperature between 15 and 20° C, cloudiness and relatively dry weather with the afternoon relative humidity between 40 and 60% may be optimum for triggering pest population of tea mosquito bug in cashew. Tea mosquito bug is a menace over the West Coast and coincides with flushing and flowering time of cashew. The cold (< 12°C of minimum temperature), hot (>35°C of maximum temperature) and wet (Continuous heavy rains) weather conditions may not be conducive for triggering pest population. Continuous cloudiness (< 2h/day) consecutively for five days during second week of December, immediately followed by continuous dewfall under ideal thermal and humid conditions may not only trigger the growth of the fungi but help in the sporulation, multiplication and spread of the Inflorescence blight in cashew during 1998-1999. Interestingly, there is a lead - time of one month between incidence of disease and crop damage. Such studies will be of immense use in integrated pest management to overcome menace of tea mosquito bug in cashew.

Climate and cardamom

Small cardamom (*Elettaria cardamomum* Maton) - popularly known as the Queen of Spices - is indigenous to the evergreen rain forests of the Western Ghats. It is confined to the States of Kerala, Karnataka and Tamil Nadu, accounting for an area of 41,288 ha, 25,947 ha and 5,085 ha, respectively. Among these States, Kerala accounts for major production (72.4 %), followed by Karnataka (20 %) and Tamil Nadu (7.6 %). The natural habitat of cardamom is the high ranges between 1000 and 1500 m AMSL across the Western Ghats and characterized by cool-humid- microclimate, which provides ideal conditions for cardamom cultivation. The annual rainfall and rainfall during the South West monsoon (June-Sep) increase from South to North across the cardamom tract and the West (Kerala and Karnataka) of the Western Ghats receive more rainfall when compared to that of East (Tamil Nadu). The reverse trend was noticed during post monsoon (Oct-Nov) and winter (Dec-Feb) and the East receives more rainfall than West of Western Ghats. In summer (Mar-May), Kerala and Tamil Nadu receive relatively more rainfall than Karnataka. The mean annual rainfall of cardamom growing areas vary from 1400 mm over Tamil Nadu to 2600 mm over Karnataka (Fig.9). The number of rainy days varies from 80 to 130 days. A declining trend was noticed in annual rainfall at all the locations except Pampadumpara and Madikeri. Similar was the case during the South West monsoon except Madikeri. In other seasons, no such uniform increasing or decreasing trend was noticed across the cardamom tract except Thandikudi, where rainfall was declining in all the seasons, The forests exert a domineering influence on soil, water resources and microclimate of cardamom. In the turn of twenty-first century, forests constituted only 24% when compared to 70% in the middle of nineteenth century in Kerala. The fast-dwindling forest cover and its consequence over climate are the concern across the cardamom tract of Western Ghats.

The surface air temperature and its range were high (5.3 -15.9° C) over Karnataka, followed by Kerala (5.2 -11.7° C) and Tamil Nadu (6.9 -10.7 ° C) across the cardamom tract of Western Ghats. Majority of locations showed increasing trend in annual maximum temperature and it was true in South West monsoon and post

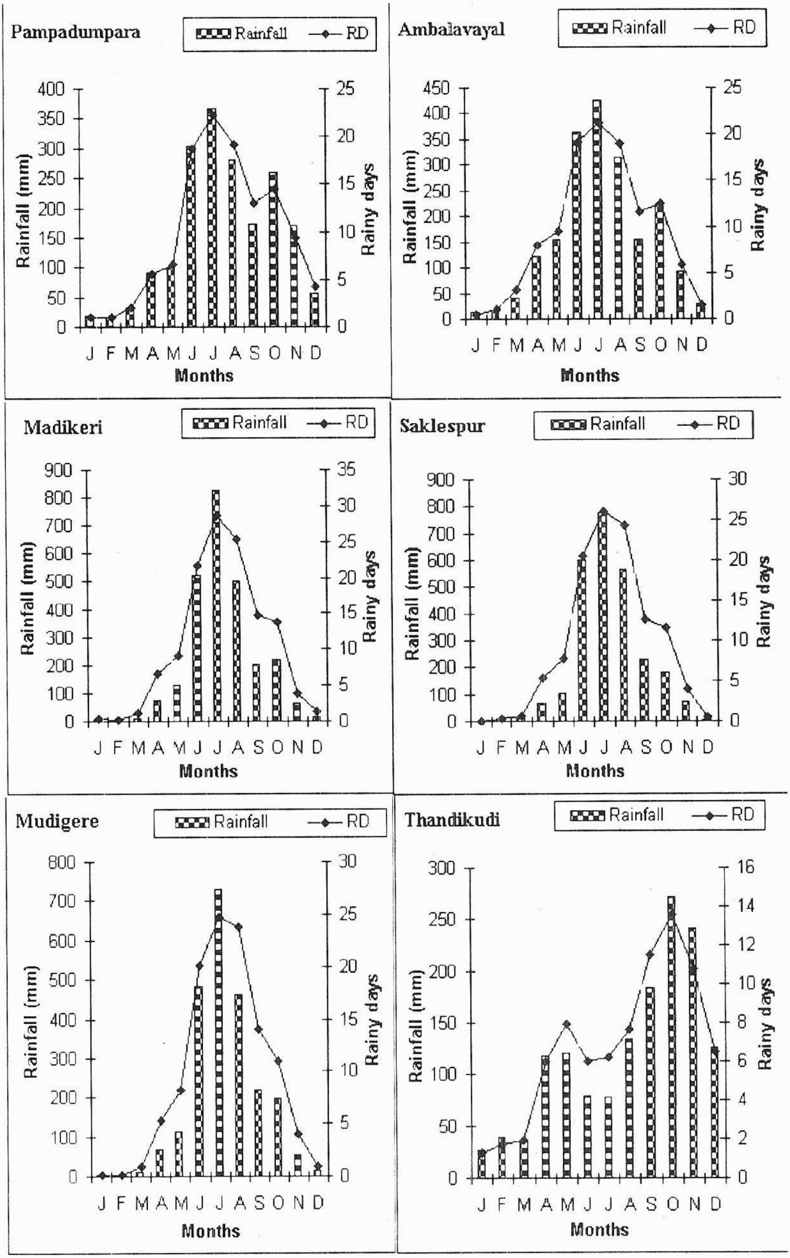


Fig.9 Monthly rainfall distribution over the Western Ghats (Cardamom, Coffee and Tea growing areas)

monsoon periods while declining during winter and summer. Interestingly, an increasing trend was noticed in majority of locations in case of minimum temperature also. The mean annual maximum temperature across cardamom tract is the lowest (24.1°C) over Tamil Nadu and the highest (26.9 – 30.0°C) over Karnataka while intermediary over Kerala (24.6 – 27.4°C). The minimum temperature ranges from 15.4 to 17.8 °C, dropping down to 13.0°C over Tamil Nadu occasionally (Fig.10). Coffee and tea are grown under the identical thermal and moisture regimes of cardamom .

Production and productivity of small cardamom were in increasing trend though a sharp decline was noticed in cardamom area across Western Ghats. This could be attributed to technological interventions since last three decades. However, the inter-annual fluctuations in cardamom production were common due to weather aberrations. For example, the cardamom production was badly hit during 1983 due to unprecedented drought that occurred from November 1982 to May 1983 across the cardamom tract of Western Ghats. Similar was the drought during 2003-04 over Kerala. It is also noticed that the cardamom production over Kerala in recent years was also badly hit due to dry spells that occurred during monsoon of 2002 and 2003. There existed a strong relationship between dry spells and cardamom production and the climate risk is more over the Karnataka region when compared to other regions across Western Ghats. The area decline in cardamom could be attributed to instability in prices and climate variability in terms of decrease in rainfall and temperature increase over cardamom tract of Western Ghats due to deforestation.

Climate and coffee

Coffee is grown at higher elevation across Western Ghats between 750 m and 1200 m AMSL. Robusta and Arabica are the two traditional cultivars grown over the high ranges along Western Ghats, covering three States viz., Karnataka, Kerala and Tamil Nadu. The major factors that affect production of Arabica and Robusta are lack of blossom and backing showers during summer months as the coffee growing areas experience uni-model rainfall. The uni-model rainfall means heavy rains during summer monsoon (June-

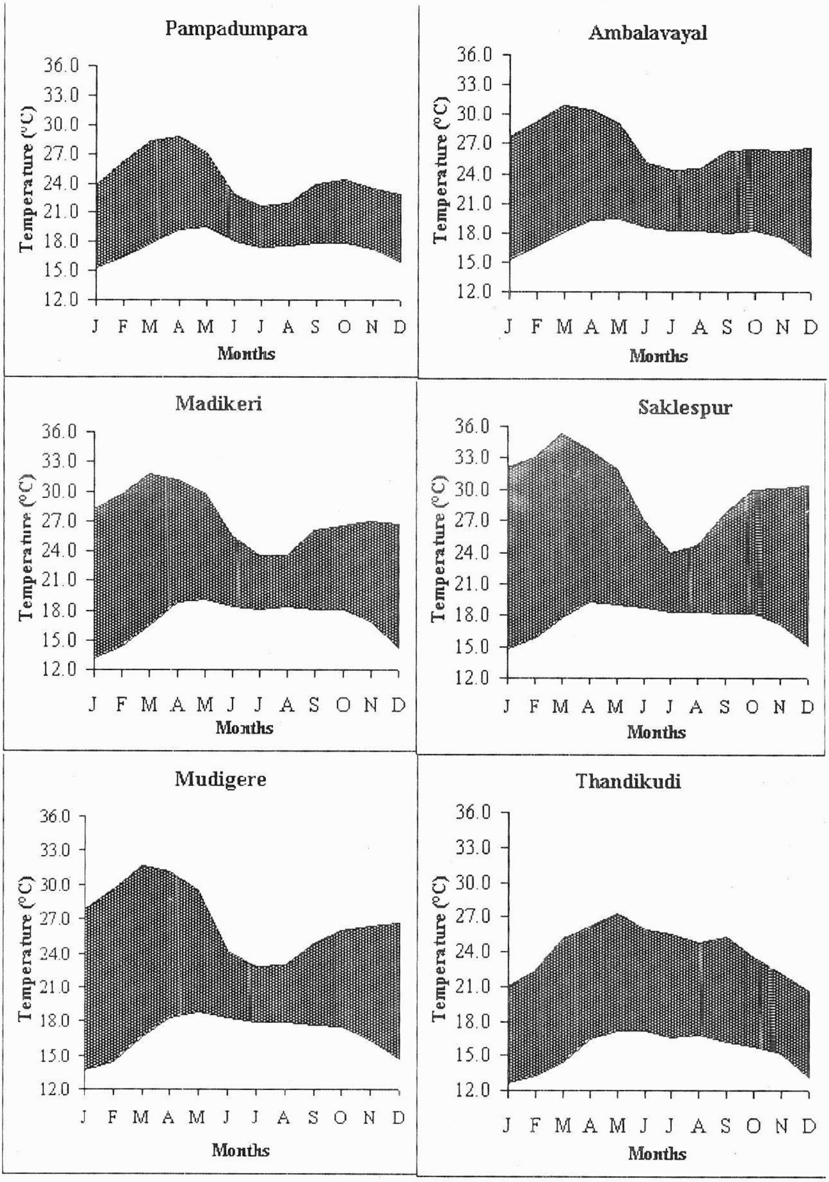


Fig.10 Temperature regime over the Western Ghats (Cardamom, Coffee and Tea growing areas)

September), followed by prolonged dry spell from November to May. Heavy rainfall during monsoon leads to waterlogging while continuous cloudiness restricts uptake of nutrients as evapotranspiration demand is low. The Indian summer monsoon lands over coffee tract around 1st June and normally between 25th May and 8th June. Once monsoon commences, heavy downpour of rains are expected during June and July with cloudy weather and overcast sky. The normal annual rainfall across the coffee growing tract varies widely between 1400 and 4000 mm. About 80% is recorded during monsoon months of June, July, August and September. Number of rainy days varies between 20 and 27 in a month during peak rainy months and July is the rainiest month, followed by June and August. The mean monthly maximum temperature is always less than 30°C while the minimum temperature revolves around 24°C and thus the surface atmospheric temperature range is 6 - 7°C only. The crop is also sensitive to wind disturbances and light conditions. Arabica and Robusta, popularly grown across

Weather effects on Arabica and Robusta across the Western Ghats

Climatic factors	Arabica	Robusta
Lack of blossom showers	Absence of rains in March – April	Absence of rains in March
Rain on opening day of blossom	Partial to complete failure	Partial failure
Hail storm	Injure the floral and Vegetative phase	Partial failure
Backing showers	Absent in May- poor crop set	Absent in April- poor crop set
Severe western exposures (with lowering of sub-soil-soil moisture)	Partial to complete	Partial to complete
Excessive wetness and waterlogging	Partial to complete	Partial to complete
Wind	Both are sensitiveto wind disturbance	

the West coast, respond differently to various weather elements. The two cultivars are also well demarcated with elevation of growing environment as Arabica prefers high altitudes when compared to that of Robusta, indicating that Arabica is relatively tolerant to low temperature and humidity when compared to that of Robusta. Growth of coffee across coffee tract appears to be affected when exposed under open conditions due to high temperature during summer and low temperature during winter.It requires a certain degree of shade for its better performance. Similar is the situation in cardamom also.

The annual rainfall across the coffee tract varies between 1400 mm over Tamil Nadu and 2600 mm over Karnataka. It revolves around 2000 mm over Kerala. The annual number of rainy days varies between 80 and 130 over the coffee tract. Bi-model distribution of rainfall is noticed over some of the coffee growing areas at Pampadumpara, Ambalavayal and Thandikudi due to both The Southwest and Northeast monsoons. The coffee tract in Kerala receives about 60 % of annual rainfall during rainy months (June-August) while Karnataka receives about 75% and 20% only over Tamil Nadu. Interestingly, the monthly rainfall is high from August to December over Tamil Nadu due to influence of Northeast monsoon unlike other coffee growing locations. Uni-model rainfall distribution is noticed over Karnataka, having the highest monthly rainfall from June to August when compared to Kerala and Tamil Nadu across the coffee tract as seen in Fig. 9. At the same time, Karnataka receives insignificant rainfall from December to March, indicating that the coffee plantations are under moderate to severe soil moisture stress if the pre-monsoon showers fail. It is not the case across coffee tract of Kerala and Tamil Nadu. It reveals that the coffee tract over the highranges across the West Coast is characterized by heavy rainfall during June, July and August except at Thandikudi (Tamil Nadu). The prolonged dry spell from December to March coupled with high rates of evapotranspiration results in the rapid depletion of soil moisture and surface water sources. Both these phenomena - high water surplus during June – August and severe water deficit during December – May affect adversely productivity of coffee plantations. It is more relevant over the

Maharashtra while in July and August over Gujarat, West Bengal, Orissa, Bihar, Uttar Pradesh and Assam, led to floods. Heavy rains again in September in Andhra Pradesh, Karnataka and Kerala led to floods and thus the year 2007 can be declared as the flood year in India. A huge crop loss was noticed in several states of the Country due to floods in *kharif*, 2007. A major food shortage is expected in majority of African countries due to heavy floods, which devastated several crops in the region. Mali, a west African country more often plagued by droughts, received unprecedented rains during 2007. Similar was the case in Algeria, Uganda, Sudan, Ethiopia and Kenya.

The Indian economy is mostly agrarian based and depends on onset of monsoon and its further behaviour. The year 2002 was a classical example to show how Indian foodgrains production depends on rainfall of July and it was declared as the 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 19.1%. Similar was the case during all-India drought in 1979 and 1987. Occurrence of droughts and floods during Southwest monsoon across the Country affects foodgrain production to a greater extent as evident from (Fig. 2.) It is one of the reasons

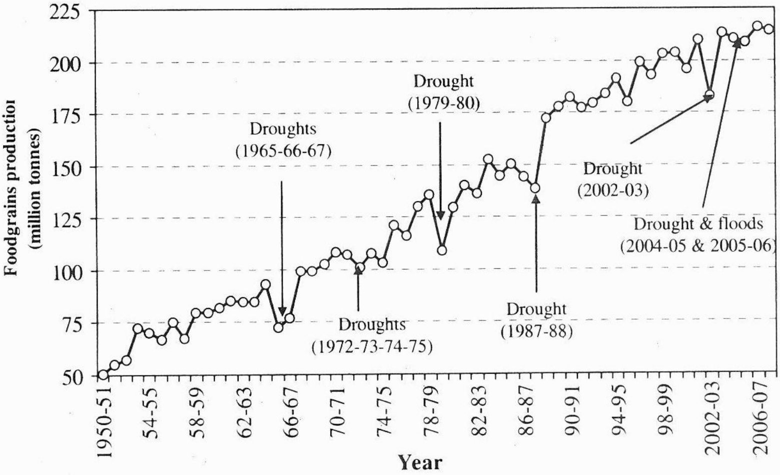


Fig. 2 Impact of droughts on Indian foodgrains production from 1950-51 to 2007-'08

Karnataka Coffee Plantations when compared to that of Kerala and Tamil Nadu.

The mean annual maximum temperature of coffee tract varies between 24 and 30°C while 15 and 18°C in minimum temperature. The coffee tract of highranges over Karnataka experiences the highest maximum temperature during March, varying between 31.6 and 35.3°C while the night temperature in January varies between 13.2 and 14.8°C. In contrast, the highest maximum temperature of 27.3°C is only observed in May across eastern parts of coffee tract (Tamil Nadu) and a low of 12.7°C in January (ref. Fig 10). The mean monthly maximum temperature is high (28.8°C) in April over Pampadumpara while at Ambalavayal during March (30.9°C). The minimum temperature at the above locations is in January and 15.3°C at both locations. It reveals that maximum temperature during summer is high over Karnataka and low over Tamil Nadu across the coffee tract. It is intermediary over Kerala. January experiences the lowest temperature at all the locations, varying between 12.7 and 15.3°C. The maximum temperature drops down significantly during summer monsoon, which is a climatic characteristic feature in the humid tropics due to heavy and continuous rainfall.

Relatively uniform temperature range (difference between maximum and minimum temperatures) is maintained (6.9 -10.7°C) over Tamil Nadu, followed by Kerala (5.2 -11.7°C). It is high (5.3 - 15.9°C) over Karnataka (Fig 11). The surface air temperature and its range are high over coffee tract of Karnataka and Kerala when

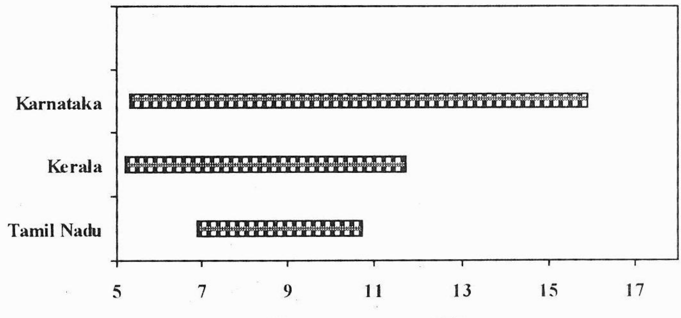


Fig.11 Temperature range (°C) over the Western Ghats (Cardamom, Coffee and Tea growing areas)

compared to that of Tamil Nadu. It can be attributed to altitudinal difference across coffee growing tract. It also reveals that the climatic risk is high over Karnataka Coffee Plantations.

The "Monsooned Malabar Coffee" is processed at Mangalore, located in Coastal Karnataka. The processing location experiences heavy rainfall of more than 1000 mm in July, followed by 957 mm in June and 605 mm in August. Out of 3264 mm of annual rainfall, 2852 mm is received during the monsoon period. It accounts more than 80% of annual rainfall. Similar is the case over Kasaragod District, adjoining to Mangalore. The maximum temperature round - the - year varies between 29 and 33.5°C. April is the hottest month while January is the coldest (around 20°C). The night temperature round - the - year ranges from 20 to 26°C. Being located in the tropics along the West Coast, the crop processing environment in terms of surface air temperatures is relatively uniform throughout the year. However, the maximum temperature dips during monsoon months irrespective of coastal or high lands and the difference in day and night temperatures is relatively less (5-7°C) when compared to that of other months. The monthly temperature range appears to be high (around 12°C) in December. It reveals that continuous high rainfall (>2500 mm) together with moderate night and day temperatures (24-30°C) during monsoon season appears to be conducive for coffee bean processing as the processing units are located along coastal belt. It is the reason why the 'Malabar Region' is chosen, where coffee beans processed and marketed are characterized with unique monsoon features. It appears to be optimum for coffee beans processing during monsoon period. Water vapour in atmosphere during monsoon period is such that the vapour pressure deficit is naturally maintained at minimum level with gentle marine breeze of three to six km/hr. The relative humidity during the night and forenoon revolves more than 90% which drops down to 70-80% in the afternoon on many occasions during monsoon months. It reveals that high atmospheric humidity together with moderate temperature and gentle marine breeze with low vapour pressure deficit accompanied by continuous heavy rains during the monsoon season are the characteristic features of the Malabar Region. These peculiar climatic features along West Coast (Malabar Region) in the humid tropics may be conducive for coffee beans processing.

Climate and tea

The Nilgiri hills lie in the tropics but have a varied climate owing to their altitude. The lower hills are tropical, the middle hills are sub-tropical while the higher hills are temperate. It has been observed that in the last four decades, much degradation of the forest cover has taken place in the district leading to ecological imbalance mainly because of large cultivation of plantation according to the naturalists and conservationists. Investigations made on drought from different climatological parameters for the period from 1938 to 1966 revealed that about 40% of the years visited drought including severe and disastrous ones (Samraj, 1996). Two growth periods are seen in tea (mid-March to mid-June & mid-August to mid-November). The frequent water shortage in April and May for main crop and November and December for second crop had definite effect on low out turns from larger areas in Nilgiris District. Irrigation during cool dry season (mid-January to mid- March) will not produce desired effect on production as temperature is the limiting factor during the period. Irrigation during the hot and dry period (March to September) that occurs frequently in Nilgiris will be beneficial in crop production. Summer droughts experienced in 1983, 1985, 1987 and 2004 across the Western Ghats adversely affected tea leaves production too.

Night temperature and relative humidity are the most important factors which determine productivity of tea in addition to rainfall. In Annamalai, night temperature occasionally drops below 5 °C and humidity is below 70% when the dry atmosphere is prevalent. This situation leads to tea production at lower levels. In tea, there is a time lag between the physiological function of tea bush and the vegetative harvest. It is about five weeks in the pruned year and four weeks in other years. As such the weather conditions of the previous month are generally correlated to the current month's harvest (Rao, 2005).

Drought management in tea plantation begins from planting. Healthy and strong composite plant obtained by grafting the productive clones on drought tolerant stocks proved beneficial. Deeper planting pits promote better root system. Certain management practices like provision of live shade, mulching, early centering and drip/sprinkler irrigation during the moisture periods boost the growth and sustain the bio mass production. Addition of new mature leaf in the canopy before the dry spell reduces the impact of drought. Foliar application of NK and polymer based antitranspirants bring in favourable gas exchange through osmaticum and stomatal regulation. Consequently impact of drought is minimized (Manivel and Kareem, 1996). About 50% reduction in green tea leaves was noticed in April 2004 when compared to 2003 and 2005 in Himachal Pradesh due increase in maximum temperature of the order of 2.1 to 7.9°C in March (Prasad and Rana, 2006). In apple, flowering was advanced by 15 days and fruit set was very poor.

Effect of maximum temperature in March 2004 on Apple and Tea in Himachal Pradesh

Apple	Tea
Flowering was early by 15 days	About 50% reduction in green tea leaves in April when compared to 2003 and 2005
Large – scale flower drop due to	The yield reduction was seen only after one month.
acute moisture stress heavy rainfall during second fortnight of April	Heavy losses in yield were noticed in Potato (matured ahead), vegetables and pea
accompanied by sharp fall in temperature caused poor fruit set	Potato (matured ahead), vegetables
Optimum temperature for fruit blossom and fruit set is 24°C while the region experienced above 26°C for 17 days.	

Climate and cocoa

Rainfall preferably between 1500 and 2000 mm annually with a dry season of not more than three months with less than 100 mm/ month and temperature varying between 30-32° C as mean maximum and 18-21° C mean minimum with an absolute minimum of 10°C are the climatic boundaries desirable for growing cocoa.

The loss of apical dominance in cocoa is seen constantly at a temperature of above 32oC. Loss of apical dominance means development of side shoots of plant. As in other fruit crops, duration of pod, its size and quality and pod development are controlled by surface air temperature. A decline of 39 % in annual cocoa yield was noticed in 2004 when compared to that of 2003 due to rise in maximum temperature of the order of 2-3° C from 14th January to 16th March, 2004 along with prolonged dry spell. Such trend was noticed whenever summer temperature shoots up by 2-3°C when compared to that of normal maximum temperatures of 33-36.5 °C. The adversity of weather aberrations on rhythm of normal growth of cocoa is reflected in yield after a lag period of 4 - 5 months.

High rainfall has a malevolent effect, where crop is grown under waterlogged conditions while summer rainfall has a benevolent effect with yield. On augmenting dry season's rainfall by irrigation, the results have not always been very marked; because the water lost from the leaves is so high with low humidity that the roots cannot match the loss. Crop yields are very low with heavy shade and increase with increasing light up to 50 % level. Cocoa yield is affected by presence or absence of fertilizer if the level of light is above 50%. With added fertilizer, yields increase almost up to full light, whereas in absence of fertilizer, yields fall off. The theory has therefore been advanced that the light regime for optimum yield of cocoa is a function of its mineral nutrition.

Climate and coconut

The coconut is a tropical tree plant as its distribution in the world is confined almost entirely to tropical zone. In fact, it is highly adaptable to a variety of environmental conditions though it does exhibit some growth preferences. The West Coast of India, the major coconut belt of the country, rainfall varies from 1500 to 3500 mm or more/annum and the crop is grown under rainfed conditions. Within the State of Kerala, the per palm production is much better towards South due to uniform distribution of rainfall as the palm grows under rainfed conditions. High rainfall during heavy rain months (June-August) adversely affects coconut yield due to waterlogging and lack of aeration. Heavy button shedding is likely under waterlogged and severe soil moisture stress conditions. In non-traditional areas like Tamil Nadu, Andhra Pradesh and Karnataka, coconut palms are grown commercially under irrigated conditions only, otherwise crop does not come up due to climate extremes in terms of surface air temperature and poor annual rainfall of about 1000mm. Of all the climatic factors affecting the coconut, rainfall appears to be the most important under rain fed cultivation. There is a lag period between influence of meteorological variables and crop yield in coconut as initiation of primodium takes place 44 months before harvest. The yield of a particular year was influenced by January to April rains for two years prior to harvest together with rains during same period of the year of harvest (Patel and Anandan, 1936). Park (1934) found that severe drought experienced in puttalam (Srilanka) affected yield of nuts for a period of about two years with the maximum effect at about 13 months after conclusion of drought. Decline in monthly nut yield was noticed in the following year from February 1984 to January 1985 due to severe drought of summer 1983. The effect of drought on monthly nut yield was noticed in the eighth month after drought period was over with a maximum (64.1%) reduction in nut yield in July 1984 (ie, 13 months after the drought period was over) and the minimum (23.6%) in January 1985. Similar was the case during 1988-89 (Fig. 12). The recent summer drought

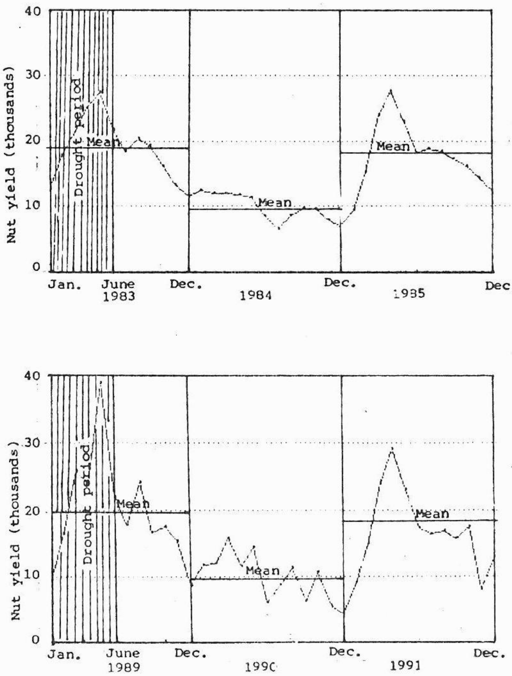


Fig. 12 Effect of drought on coconut yield at RARS, Pilicode (Kerala)

during summer, 2004 also adversely affected coconut yield to some extent over Kerala. In the semiarid tropics like Tamil Nadu, heavy crop loss was reported due to continuous failure of rains in 2001 and 2002 and lack of irrigation due to poor water recharge in wells. Coconut palms show the following characteristics under severe soil moisture stress depending upon duration and intensity of drought (Rao, 2002).

Withering and mortality in young seedlings under poor management

Drooping, wilting and drying of lower whorl of leaves

Breakage of leaves at petiole or just above it

Spindle leaf breaking which lead to mortality in senile palms under conditions of poor management

Abortion of spadices, starts from October/ November onwards

Button shedding and immature nut fall

Nut size decline and

Finally decline in nut yield in subsequent year up to 50% depending upon the type of management and genotype

In fact, it is temperature that sets limit to latitude and altitude up to which coconut can be successfully cultivated. The farther one goes from equator the more is the palm confined to lowlands. It is restricted to an altitude of 600 m AMSL, beyond which it is not economic as crop comes up very late for bearing and nut development process takes too long a period. Hence, the coconut palm likes equable temperature neither very hot nor very cold. The optimum mean annual temperature for better growth and maximum yield is 25-27°C with a diurnal variation of 5-10°C. The coconut palm grows under profuse irrigated conditions where the range of variation in temperature is considerable as seen in Tamil Nadu, Karnataka and Andhra Pradesh. On the West Coast of India, the monthly mean minimum temperature does not fall below 20°C and the mean monthly maximum rarely goes above 33°C. In Malaya maximum temperature varies from 30 to 32°C on the coast and 34° to 37°C in the inland. The diurnal variation in temperature is similar to that of 5-10°C. High temperature causes drying up due to desiccation of inflorescence in primordial stage. These would normally open 16 months later in monsoon season and because of their abortion, the leaves, which subtend them, show up barren axils. Abortion of spadices is influenced by high temperature prevailing during hot weather season. The second phase of nut development in coconut is sensitive to heat units since it is the critical phase, which finally decides nut size in coconut. If the number of heat units during second phase of nut development (4-7 months old nut) is more than 2100 day °C, the final nut size may be diminished. Due to high maximum temperature and low humidity, oil content is relatively less in non traditional areas. It clearly indicates that number of heat units influence crop duration, nut size, oil content and nut yield to a large extent. The genetic coefficients are derived for each crop based on thermal units and used in crop growth simulation models, which are widely operational for decision making. Strong winds are not desirable as they considerably damage coconut plantations. They not only uproot or break the stem but also twist the crown or break the leaves and destroy considerable part of the crop. Heavy and extensive damage to coconut palms due to cyclones are reported from Philippines, South India and Jamaica due to strong winds.

It is well known that climatic factors do greatly influence incidence and intensity of pests and diseases. On West Coast of India, incidence and severity of the pests such as rhinoceros beetle (*Oryctes rhinoceros*) and black-headed caterpillar (*Nephantis serinopa*) are more in summer. Again large scale emergence of cock chafer grubs (*Leucopholis coneophora*) on the West Coast is noted only about a fortnight after onset of South West Monsoon in sandy and sandyloam soils. Regarding diseases, the incidence of bud - rot and leaf – rot diseases of coconut palm is always noticed in a severe form only in rainy months when atmospheric humidity is high. The stem bleeding is prevalent in northern districs of Kerala, where heavy rains during monsoon followed by prolonged dry spell are noticed.

A steep increase in coconut price was also seen in 1984 due to low coconut production in Kerala as a result of summer drought in 1983 and for the first time, the coconut growers got a high premium of more than Rs. 2200/ quintal of copra. Under open auction sale, on an average Rs. 3.07/ coconut was obtained at the Regional Agricultural Research Station, Pilicode in 1984 as against Rs. 1.70/ nut in 1983. Such trend was seen in lean crop years. A sudden price hike was also noticed from 2002 to middle of 2005 due to low coconut production over Kerala and a large number of coconut palms withered in Tamil Nadu due to all India drought 2002. Of course, the coconut price in Kerala depends on several factors viz. import-export policy, total coconut production outside Kerala, less edible oil consumption and coconut oil use in industries as several substitutes are used in place of coconut oil. Import of palmolene oil may be one of the major contributing factors in deciding coconut oil price. Of course, this is to highlight the role of climate variability on coconut price and as such the subject area of coconut price and production and vice versa is beyond scope of the study.

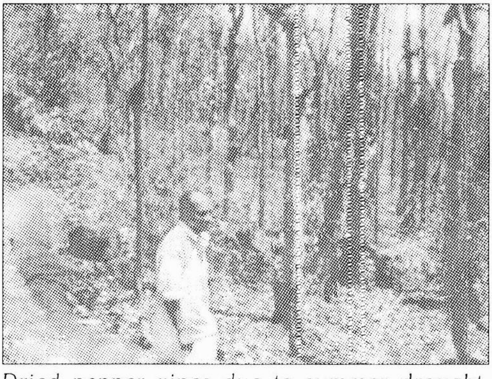
Climate and arecanut

The arecanut palm is capable of growing under a variety of climatic and soil conditions. It grows well from almost sea level up to an altitude of 1000 m in areas of abundant and well distributed rainfall or under irrigated conditions. Arecanut is mostly grown in valleys under profuse irrigation in summer. Arecanut may not come up well under waterlogged conditions. The climatic requirements of arecanut appear to be similar to that of coconut, but for relatively sensitive to soil moisture stress in low and mid lands (Rao, 2005). The crop is also grown in mid-and-high lands under rainfed conditions. However, the yield appears to be relatively less under rainfed conditions when compared to that of irrigated crop. Under drought conditions like summer 1983 and 2004, the crop output is very low and mortality of arecanut palms also evident in poor crop management situations under rainfed conditions. Studies on effect of climate variability and yield in arecanut is very scarce and therefore it needs attention from researchers so as to mitigate the ill effects of weather aberrations through better crop management practices under rainfed as well as irrigated conditions.

Environmental variables play a vital role in manifestation of visible symptoms in the yellowing affected arecanut palms. A general decrease in yellowing was observed in all the toposequences viz, converted paddy field, garden land and terraced upland during post monsoon compared to pre monsoon season. Arecanut grown in converted paddy field recorded the highest percentage decrease in yellowing of 60 percent compared to 11 percent in garden land and 47 per cent in terraced upland. Thirty five out of 50 palms belonging to the moderate group during pre monsoon have become mildly affected during the post monsoon season. However, this was only 5 per cent in the garden land and 58 per cent in terraced upland as per the study conducted in Kerala Agricultural University. The high atmospheric and soil temperature and consequent higher evapotranspiration might have interfered in the maintenance of suitable soil nutrient environment and uptake, translocation and metabolism of nutrients resulting in increased yellowing of leaves (Jacob et al., 2005).

Climate and black pepper

Black pepper, the "king of spices" continues to be the largest exported spice of India. It accounts for more than 40 per cent of the value of spice export. Pepper requires a warm and humid climate. An annual rainfall of 2500 mm is ideal for proper growth of crop. Rainfall is believed to be the chief pollen vector in pepper. The flowering process in pepper is initiated by the application of water equivalent of 70 mm or more rainfall within the period of three weeks, followed by a dry spell. Rainfall influences the flower bud differentiation process. Spike elongation and berry development in pepper may be ceased if there is prolonged dry spell immediately after good summer showers. Hence, good summer showers followed by a dry spell may be detrimental to black pepper production. Moderate and continuous



Dried pepper vines due to summer drought, 2004 in Wayanad rainfall till berry initiation may be favourable to black pepper. It may not come up well in areas, where low temperature prevails throughout the year (Rao, 2005). A break in the rainfall for even a few days at stretch occurring during any part of the critical period of reproductive phase of the pepper plant will affect pepper yield considerably.

The intensity and distribution of summer showers in any year determined to a considerable extent the crop prospects of black pepper in that particular year. A dry spell from February to April should prevail for satisfactory spiking in pepper. In an year of poor or no summer showers black pepper yield is satisfactory. On the other hand, fairly high summer showers result in low yield of pepper (Kannan et al., 1987). Mixed cropping of coffee and pepper is more suited to areas like Waynad instead of monocropping with coffee or pepper to ensure reasonable net returns from a unit area as both the crops responds differently to a particular rainfall distribution. The black pepper gardens in Wayanad District were adversely affected and some of them wiped out due to severe drought in summer 2004. High day temperature in addition to hydrological drought led to the mortality of pepper gardens.

Climate and rubber

Rubber can be grown from almost sea level up to an altitude of 500 m in areas receiving a well distributed annual rainfall of not less than 2000 mm with a warm, humid equable climate (21 – 35°C). The rate of growth is maximum in rainy season when compared to summer. Hence, high rainfall during summer as well as during monsoon has positive effect on rubber as it is grown only under rainfed conditions in traditional zones (Rao, 2005). The latex yield depends upon various parameters that affect the flow characteristics of latex and in vitro regeneration of rubber. Severe drought will reduce rubber yield by affecting these two mechanisms (Nair et al., 1996).

Droughts of even severe magnitude both in terms of uneven distribution and reduced total annual rainfall can strike the state in future years. For economic reasons rubber is generally considered as a rainfed crop. Irrigating rubber plantations during moisture stress period will not be either economical or feasible. Adoption of appropriate management practices towards conservation of water and soil can go a long way in addressing drought situations. The total annual yield during 2002 was not affected due to meteorological drought of monsoon 2002 though a slight depression was noticed in few cases during September when rainfall was unusually low. However summer droughts like 1983 and 2004 adversely affected the latex yield to a considerable extent. If the water stress is more during the summer, the latex yield in rubber is less and vice-versa.

The effect of climatic factors on perennial crops like coconut is different from that of annual crops. In the latter, the effect is limited to short period of crop season and is manifested immediately, in the

Occurrence of cold wave (frost and cold spell) during December-January, 2003 and its effects (after Samra et al, 2004)

States affected	Crops suffered	Percentage loss	How to reduce the impact (?)
Parts of Jammu, Punjab, Haryana, Himachal Pradesh, Bihar, Uttar Pradesh and North Eastern States.	Mango, Litchi, Guava, Papaya, Ber Kinnow, Pine apple, Sapota, Amla, Assam lemon, Jack fruit and Peach	10-100% depending upon crop and variety within the crop (mango	Proper selection of fruit species / varieties, wind breaks or shelter belts, frequent irrigation, smoking, covering young fruit plants with thatches or plastic shelter and air mixing
	Fruit size and quality were affected in horticultural crops	Damage is more in low - lying areas where cold air settled and remain for a longer time onground	
		Temperate fruits such as apple, plum and cherry gave higher yield due to extended chilling	Weather forewarning

former, the effect may be felt then or, as is more often the case, may be discernible only after some time lag. Thus what is claimed as the effect of a particular season may not in fact be due to that season alone but may also be partly due to delayed effects of a foregone season. These are inevitable on account of peculiar growth features exhibited by the crop. Extreme weather events like droughts and floods, cold and heat waves (Samra et al, 2004) adversely affect crop production to a large extent. At the same time, effects of extreme weather events persist for more number of years in plantation crops depending upon crops' phenophase.

Though ill-effects of abnormal weather events are well understood in agricultural sector at the field level, it is difficult to quantify the same at the zonal/state level based on secondary data. Hence, a realistic scientific method is to be evolved as such no technique is available to project future crop trends in plantation crops based on climate variability/change. Warming with decline in rainfall and increase in temperature range is projected at some of the locations across the high ranges along the West Coast, where cardamom, coffee, tea and black pepper are predominantly grown under the influence of forest-agro-eco-systems.

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Climate change risk management in Agriculture

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Introduction

Global warming is the result of the rising atmospheric concentration of carbon dioxide mainly owing to the burning of hydrocarbons or fossil fuel such as petrol and diesel. The distribution of forests and their degradation too have contributed to the rise in carbon dioxide levels. 93 per cent of greenhouse gas emission over Kerala is due to burning of petroleum products and firewood. Out of this, the share of carbon dioxide emission from burning fuel is 80.47 per cent according to the State of Environment Report (SoER), 2005. Methane emission in terms of global warming potential accounts for 17.58 per cent while two per cent in the case of nitrous oxide emission in Kerala. The total consumption of petroleum products in the State in 2003-04 was 30.88 lakh tonnes, out of which 85 per cent is carbon. Methane is emitted from water bodies including paddy fields and during coir retting. A total of 13.6 lakh tonnes of husk is processed annually through retting in the State.

The trend in monsoon and annual rainfall of Kerala was declining since last 60 years though it is stable if we consider annual rainfall since 1871 onwards (137 years). The State of Kerala is also moving from wetness to dryness within the humid climate (B4 to B3). For the first time, the monsoon rainfall over Kerala was short by 33% and July deficit was 39% in 2002, which was declared as the all India drought at the national level. A drought like situation was noticed during the monsoon in Wayanad District, where the deficiency of rainfall was 55% during 2002. During the last 43 years, the mean maximum temperature has risen by 0.8 degree

Celsius , the minimum by 0.2 degree Celsius and the average by 0.5 degree Celsius over Kerala according to India Meteorological Department in the wake of the Intergovernmental Panel on Climate Change (IPCC). February and March are the hot months in Kerala, with a mean maximum of 33°C. Palakkad recorded the highest temperature of 41°C on April 26, 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 of 2004, which was one of the severe summer droughts in Kerala. The production of thermo-sensitive crops like black pepper, cocoa and cardamom were adversely affected due to rise in temperature in summer 2004. The lowest temperature recorded was 12.9°C at Punalur on January 8, 1968. The possibility of cyclone activity and storm surges may increase in oceanic basins of the Arabian, Indian and Bay of Bengal due to global warmning. Sea level increase is likely as projected globally. The weather extremes like occurrence of droughts and floods and heat and cold waves are likely to increase. These weather extremes adversely impact Kerala ecologically and socio-economically. Kerala experienced severe summer droughts in 1983 and 2004 while floods during monsoon in 2005 and 2007. The crop losses were considerably high during the above weather extremes.

Landslides

High rainfall and manmade interventions lead to landslides in Kerala as it consists of topographical features like plains, valleys, slopes and mountains, where agriculture is intensively practiced. It results in damage to crop lands in addition to human and infrastructure losses. As projected, the landslides are likely to be more frequent in ensuing decades. In 2005 and 2007, the number of landslides noticed across the State was more due to heavy rains received during the monsoon season. Indiscriminate construction of checkdams and rainwater harvesting systems could have triggered the destructive landslide in Vadakara and Koilandy taluks of Kozhikode District in early July in 2005. It resulted in destroying of standing crops about large tracts in the downhill areas. Rainwater harvesting pits, in the absence of adequate run off, may lead to landslides as water retained may lead to saturation of the slope. At the same time, the checkdams overflow during the rainy season. Increase in rain in catchment areas lead to the formation of underground reservoirs, which exert pressure on the dam, causing it to burst. The strategy to mitigate landslides should be a two pronged one to improve slope stability.

1. Terrain specific guidelines for construction of rainwater pits and checkdams
2. Dewatering the slope before every monsoon to reduce the vulnerability. It can be done by opening up all the streams, filling up the soak pits and checking all the contour bunds for waterlogging.

The landslide prone areas are to be identified. Those areas can be avoided for domestic and agricultural purposes thus human and crop losses can be minimized.

Wayanad and Idukki agro - ecosystems

The normal average annual rainfall over the Wayanad District is 3417 mm, having 2760 mm in the southwest monsoon, 340 mm in northeast monsoon and the rest in other months. Since last 15 years, the annual rainfall and rainfall during the monsoon were declining in the Wayanad District. The District had a deficit (186 cm) of 55 per cent in 2003 and 35 per cent (191 cm) in 2002. In 2000 and 2001, it was only 255 and 207cm, respectively.

Table. Annual rainfall (cm) from 1991 to 2005 over highranges across Kerala

Year	1991	92	93	94	95	96	97	98	99	00	01	02	03	04	05
Wayanad	280	325	240	343	250	270	280	240	220	255	207	191	186	195	217
Idukki	410	380	310	385	350	387	390	425	388	322	394	315	315	383	213

Continuous decline in rainfall and rise in temperature in addition to severe summer drought in 2004 led ecosystem of Wayanad is in peril. Rainfall decline and temperature increase are projected over Ambalavayal. Several black pepper gardens were wiped out during summer 2004. There was a time when oranges were plenty in Wayanad District. At present such agro-eco systems are extinct. It was attributed to change or variability in climate and deforestation.

Conversion of large tracts of paddy fields into banana garden in addition to excessive use of chemical fertilizer and pesticides and large-scale mining of sand from rivers which began in the 1980s, have been identified as the causal factors for severe drought with continuous decline in annual rainfall. Introduction of banana in paddy lands has deprived the District large areas of wetlands that are needed to store water. With banana cultivation so extensive, nature lovers said the very name of the District (Wayanad means land of paddy fields) has lost its meaning. Groundwater depletion is so much due to over exploitation. The natural habitat of cardamom under the forest eco-system is also in peril over Idukki district due to climate variability. Rise in maximum temperature and fall in minimum temperature are projections over Pampadumpara. Widening temperatures may be detrimental to cardamom in addition to deforestation.

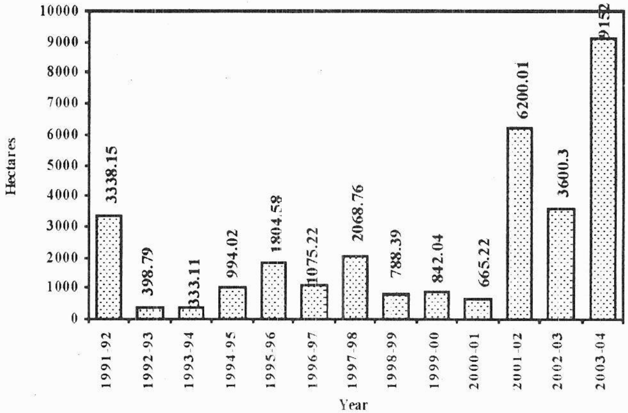
Rice wetland ecosystem

It was on February 2, 1971 that delegates from various countries signed the international convention on wetlands during their meeting in the Iranian city of Ramsar on the shore Caspian Sea. and decided to observe February 2nd as the 'World Wetland Day'. As per the Ramsar convention the theme for "Wetland Day" in 2002 is "Wetland: water, life and culture. Prolonged presences of water in wetlands elevate conditions that favour the growth of specially adapted flora and fauna. In fact wetlands are often referred to as biological diversity providing water and primary productivity upon which countless species of plants and animals depend on their survival. Wetlands are extremely effective ecosystems for the control of flood and storms and extra-ordinarily good store houses of water for drinking, irrigation and recharging of groundwater sources. Conservation of wetlands has a significance from a tourist and a cultural point of view. Wetlands comprise all types of natural and manmade water bodies including our paddy fields, reservoirs, mangroves, rivers, lakes, inundated areas, and kole lands. Area under rice was 8.75 lakhs ha with an annual production of 13.52 lakh tonnes in 1971-72. The State could meet nearly 30 per cent of its rice demand from internal production. But now the area has come down to 2.9 lakh ha (2004-05) with a production of 6.67 lakh tones, meeting only 15 per cent of its requirement. During this past four decades, the rice areas has declined by 67 per cent and the present level of production was possible because of the productivity has risen from 1575 kg to 3201 kg/ha during the years. Paddy fields are being converted to grow other profitable crops like banana, coconut, arecanut and alike, construction of structures, mining and other purposes.

One of the reasons for decline in rice cultivation in Kerala is that rice cultivation is less profitable compared to other crops. Studies at Regional Agricultural Research Station, Kumarakom proved that the system of rotating paddy cultivation with aquaculture in Kuttanad has helped to improve the rice production besides bringing in a yield upto 1000 kg of fish from one hectare of land without incurring any cost on feeds or manures. This system will also maintain the natural ecosystrems in the area. It is a fact that the rice land ecosystem promotes emission of gases like methane which add to the emission of greenhouse gases. This harmful effect can be reduced and at the same time the positive influence of the system can be utilized. In the semi dry system of rice cultivation practiced during the first crop season, the first 1-1.5 months period of rice cultivation, the field is dry and aerobic condition prevails. In the later part of second crop season, the filed is intermittently irrigated, which results in alternate wetting and drying. During the third crop season, paddy is cultivated under irrigated systems and intermittent wetting and drying is followed. In places where System of Rice Intensification (SRI) method of rice cultivation is practiced, it reduces the production of harmful greenhouse gases. Growing of oil seeds, pulses, vegetables and green manure crops in rice fallows will definitely result in an eco-friendly atmosphere. Salt water intrusion and stalinization of fertile rice land is a problem in Kuttanad (Alappuzha and Kottayam Districts), Pokkali land (Ernakulam and Alappuzha), Kaipad lands (Kannur District) and Kole land (Thrissur and Malappuram). The main problem lies in the fact that crop discipline is not followed-such as Punja crop must not be retained beyond March 15th in Kuttanad. Ensuring crop discipline and scientific cultivation will definitely help in reducing the ill effects and maintain the natural ecosystem. The intensity of ill-effects due to occurrence of droughts and floods can be minimized if wetlands are intact in a State like Kerala, where the topographic features play a permanent role in agricultural scenario.

Deforestation reduction

At present, forest utilize about 686 gigatonnes (Gt) of carbon - about 50 per cent more than atmosphere - and are being cleared at an average rate of about 13 million hectares per annum over the World. It makes deforestation responsible between 20 and 25 per cent of global greenhouse gas emissions. As many as 572 fires broke out in the forest of Kerala during 2004 summer and the average loss of forest per year during the 12 - year period (1991-2003) came to about 2,093 ha. It was more than two-and-a-half times the average annual loss that used to occur in the early eighties. The average area damaged by fire annually was only 831 ha, between 1981 and 1986. The higher incidence of fire (9152 ha) during summer 2004 was attributed to severe drought. Catchment and coastal areas are too ecologically sensitive areas in Kerala. Land use planning of catchment areas with afforestation of native species through natural growth, shola protection and aerial seeding with native seeds and closing the area from human interference for varying periods can help develop natural forests without much expenditure. This would enhance the biodiversity of the area, allow soil conservation and increase the discharge of rainwater without siltation into manmade dams.



Area destroyed in forest fires from 1991-92 to 2003-04 over Kerala

Biodiversity

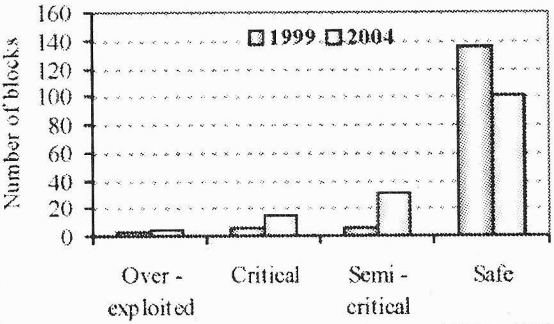
The Economic Review, prepared by the State Planning Board, 2003 warns that a third of the State's biodiversity would vanish or would be close to extinction by 2030 unless steps were taken to check extinction of species. Of the 300 rare, endangered or threatened species in the Western Ghats, 159 are in 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 10,035 species, which represents 22 per cent of Indian flora. Of these, 3,872 are flowering plants of which 1,272 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. The review recalls that during the 20th century, at least 50 plant species have become extinct in the Country. Three species of birds – Himalayan mountain quail, forest spotted owlet and pink-headed duct – have become extinct. Besides, as many as 69 bird species have been categorized as extinct. The mammals, Indian Cheetah and lesser one horned rhinoceros have also perished. The Malabar civet is on the threshold of extinction and 173 species have been listed as threatened. Among flowering plants, about 1500 species come under threatened categories. It may be noted that nearly 23 per cent of the total endemic flora species of the country are in Kerala. Of 1272 such species, 102 species occur exclusively in Kerala. Describing a conservation strategy, the review says that ecologically sensitive areas have to be identified with reference to topography, hydrological regimes and this has to be networked with species diversity.

Organic farming

The indiscriminate use of fertilizers and plant protection chemical and weedicides are polluting the soil, air and water beyond the tolerable limit. This is true in case of certain areas in Kerala where the practice is creating problem. There was drastic decline reduction in the use of organic manure for the past years. Awareness has been created on the use of organic manures among the farmers with the reasonable use of chemicals without affecting productivity.

There are certain crops and areas where organic farming can be practiced in Kerala. Organic farming plays an important role as an alternative food production process. It is a crop production system that avoids or largely excludes the use of synthetically produced fertilizers, pesticides, growth regulators and livestock feed additives. As far as possible it relies on crop rotations, crop residues, animal manures, legumes, green manures, organic wastes, biofertilizers and aspects of biological pest control to maintain soil productivity and tillage to supply plant nutrients and to control insets weeds and other pests. Input availability, productivity, premium price and marketing aspects have to be considered. In other areas, good agricultural practice with the minimum dependence of agrochemicals will definitely reduce the pollution of soil, air and water and reduce its influence in greenhouse gas emissions.

Groundwater depletion



Comparison of groundwater resources between 1999 and 2004

An increased demand and unregulated exploitation are threatening to accelerate depletion of groundwater resources in Kerala. Study by the Ground Water Department in 2004 reveals heavy imbalance in the availability of groundwater resources in the State for the past five years, with one third of the development blocks reporting higher exploitation though all the blocks were in the safe category in 1992. The data from the survey reveal that Kasaragod District taps 79 percent of the water reservoir, the highest rate of exploitation in Kerala. Thiruvananthapuram comes second with 67 per cent and Wayanad the last with 25 per cent. On an average, Kerala extracts 47% of the net annual groundwater availability. Athiyannur in Thiruvananthapuram tops the list of blocks with over exploited resources followed by Kozhikode, Kasaragod, Chittur in Palakkad and Kodungallur in Thrissur.

The monsoon rainfall was low against the normal consecutively since last six years (1999-2004) and over exploitation of groundwater in addition to the lack of water discharges from major surface reservoirs led to severe hydrological drought in 2004 resulted in severe crop losses and the State's economy was adversely affected. As the opportunity for natural percolation of rainwater is on the decrease, only negligible portion of rainwater is recharged by natural percolation from available open area. As a result, the major portion of rainwater is wasted as run off through drainage into the ocean. Because of heavy extraction of groundwater, the water level has fallen alarmingly. The destruction of forest in the catchments areas had lead to the drying up of reservoirs and the extensive sand dredging has drastically reduced the rivers' water holding capacity and percolation to groundwater.

Rainwater harvesting / groundwater recharging

Efforts are needed for effective rainwater harvesting in our farm lands. Wherever water is running we should make it walk. This is done by terracing, contour bunding, increasing the soil vegetative cover etc. All walking water should be lie down. Rainwater harvesting is unique and traditional system of recharging of the under groundwater bodies for sustained water availability. There are several techniques in rainwater harvesting which can be practiced in household (roof top rainwater harvesting) as well as fields. Traditional sources of water like very shallow, small diameter wells known as 'keni' in Waynad district, horizontal wells/ tunnels called 'Surangams' in Kasaragod district, natural wells, ponds, tanks, springs, lakes, wind breaks etc. should form an integral part of the watershed development programme. Groundwater utilization has to be based on location specific investigations and over exploitation has to be avoided.

Drought management

The State of Kerala always appears to be greenery due to heavy monsoon rainfall supported by rains during northeast monsoon. At the same time, the northern districts of Kerala and Palakkad experience prolonged dry spell from December to May if premonsoon showers fail, leading to soil moisture stress. The occurrence of drought for the State as a whole was noticed during summer 1983 and 2004. It is the lack of emphasis on conservation measures which results in the recurring of drought situation. Rainwater during the monsoon should be harnessed with small investments. If careful arrangements for conserving of water are not done in time, it could result in the drying up of even borewells and tubewells. In order to keep rivers and wells adequately replenished with water during the dry season, small sub-surface dams and anicuts up to 40-odd rivers originating from Western Ghats and flowing into the Arabian Sea are necessary. Implementation of irrigation and hydel development projects in all the valleys would automatically take care of domestic water supply, sanitation and partial flood control. As even partial measures have not been undertaken in all the river systems, the water potential in the state remains poorly harnessed. Watershed based participatory natural resource development and management schemes such as tanks, vented cross bars, diversion weirs and lift irrigation can increase and sustain irrigation, groundwater recharge, crop production and drinking water supply considerably.

Even in the worst of drought conditions, Kerala's rainfall statistics shows annual average as 1600 mm. This much of water if properly conserved and used would be plenty even to spare. The rivers of the State except one or two cease their flow with the cessation of the northeast monsoon and thereafter practically all the rivers dry up and remain dry until June for six months. It is during this period that the State tends to become drought prone recurrently. In addition, drought management practices have to be followed under field condition. Cultivation of drought tolerant crops and varieties, proper soil and water conservation practices like ploughing before the receipt of southwest monsoon and immediately before the cessation of the north east monsoon, opening basins of crops like coconut before south west monsoon, covering the basins before north east monsoon, organic manuring, organic mulching and husk burial can definitely conserve the available moisture in the soil and use water judiciously. Judicious use of water in day-to- day life and for agriculture purposes can reduce the impact of drought in Kerala. Awareness on drought management practices is the need of the hour to sustain agricultural production in the State against the weather abnormalities.

Crop insurance and weather forecasting

Natural calamities like flood, drought, landslides, lightening, heat and cold waves are not uncommon now - a - days. Both crop and farmer are to be safeguarded against these calamities. Often, the farmer who takes loan not able to repay it due to crop failure leading to hardships and suicides. Insuring farmers as well as crop become necessary against weather abnormalities. In this context, precise and accurate information on weather changes are necessary. Short, medium and long range forecasting will definitely help in weather-tune-farming so as to minimize the adverse effect of weather abnormalities taking suitable precautionary measures to lessen the harmful effects. The meteorological network has to be strengthened to disseminate agro-advisory service based on integrated weather forecasting. Pro-active measures against weather aberrations will go a long way in minimizing the crop losses against the climate disasters.

The green economy and development is likely to be the major policy decision over the world to combat the climate change effects and generate employment opportunities during this century as the industrial revolution, technology revolution and our modern era of globalization were the three economic transformations led to better world economy during the last century. Non-conventional and renewable energies can create more number of jobs even if 20 per cent of electricity is replaced by renewables. More people will be employed in Germany's enviro-technology industry than in the auto industry by the end of the next decade as per the greenpeace policies adapted. In India also, Maharashtra farmers took up to raise trees to meet Kyoto protocol provisions. They expect to sell their carbon abatement credits through the international commodities market. Internationally, the carbon finance market is expanding steadily as 107 million tonnes of carbon dioxide equivalents were exchanged in 2004 as against 78 million tonnes in 2003. The FoCs (Friends of Carbon - a Pune based NGO) is already moving among farmers in Karnataka, Andhra Pradesh, Kerala, Tamil Nadu, Goa, Chhattisgarh and Madhya Pradesh to bring more and more farmers all over India and become viable to attract the environment in the carbon commodity market. By sequestering such farm based and matured forests in addition to deforestation reduction, a long term storage of carbon in living and dead vegetation is possible. These steps will reduce the greenhouse gas emissions and it will be an eco-friendly transformation of global economy in terms of green economy and development in the 21st century. Fuel efficiency and low emission technologies, energy efficiency and power saving technologies along with changes in lifestyles should be a part of green economics and development.

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Impact of climate change on marine fisheries

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Introduction

Climate change is projected to cause massive changes in the environment which are on a scale unprecedented in the last 1,000 years. The causative factors of climate change are the greenhouse gases, *viz.*, carbon dioxide, methane, ozone and nitrous oxide. The most confident projections on the fall-out of climate change are for the amount of warming and changes in precipitation. The 20^{th} century was the warmest century in 1,000 years, the 1990s the warmest decade, and 1998 and 2005 the warmest years. The relatively steady warming in the 20^{th} century increased the mean temperature by 0.6° C. However, the projections from global warming models indicate that we may see nearly continuous warming of about 0.5° C per decade for every decade of this century. Thus each coming decade may successively add nearly as much warming as the entire 20^{th} century.

Climate change and sea surface temperature

For the marine environment, the projections are the rise in seawater temperature, salinity and sea level, drop in sea surface pH, and changes in the current, upwelling, watermass movement, El Nino and La Nina events. The Intergovernmental Panel on Climate Change (IPCC) has warned that climate change would affect the distribution and abundance of fish species. Many fish species, for instance, have a narrow range of optimum temperatures related both to the species' basic metabolism and the availability of food organisms that have their own optimum temperature ranges. The temperature sensitiveness is just a few degrees higher than those they usually experience in nature. A rise in temperature as small as

I~C could have important and rapid effects on the mortality of some organisms and on their geographic distributions. The more mobile species should be able to adjust their ranges over time, but less mobile and sedentary species may not. Depending on the species, the area it occupies may expand, shrink or be relocated with changes in oceanic conditions. Such distributional changes would result in varying and novel mixes of organisms in a region, leaving species to adjust to new predators, prey, competitors and parasites.

Considering the enormity of the problem and the need to address the issues connected with climate change and marine fisheries including sea food security and livelihood, the CMFRI has taken up a major ICAR Network Project " Vulnerability of Indian Marine Fisheries to Climate Change". In this project, time series data on sea surface temperature (SST) are being gathered and correlated with distribution and catches (as a surrogate of abundance) of marine finfish and shellfish. Trends in SST during 1961-2005 collected from Comprehensive Ocean-Atmospheric Data Set (COADS) have revealed that the annual average smoothed SST has increased from 27.5° C to 27.75° C (0.05° C per decade) along the northwest coast; from 28.35° C to 28.55° C (0.04° C per decade) along the southwest coast; from 28.30° C to 28.75° C (0.10° C per decade) along the southeast coast; and from 27.90° C to 28.20° C (0.06° C per decade) along the northeast coast of India.

Climate change and marine fisheries

The relationship between changing climatic factors and fish abundance is complicated and the diagnosis of the impact of climate change on fisheries is challenging. One of the problems in assessing the impact of climate change on fish abundance/catch is the complexity of segregating the climate-induced changes in fish populations from other human–induced changes such as fishing. Technological advancements in fishing have substantially influenced the catch and abundance thereby masking the climate-induced changes. The records on catches are influenced by economic factors such as the relative price paid for different types of fish. These non-climatic factors often obscure climate related trends in fish abundance/catch. However, water temperature can be used as a basis for forecasting the distribution and abundance of many species.

Water temperature also can have a direct effect on spawning and survival of larvae and juveniles as well as on food availability and fish growth. Most studies on climate change and marine fisheries are on inter-year time scales, such as El Nino and La Nina cycles and Southern Oscillation Index.

Projected impact of climate change on marine fisheries

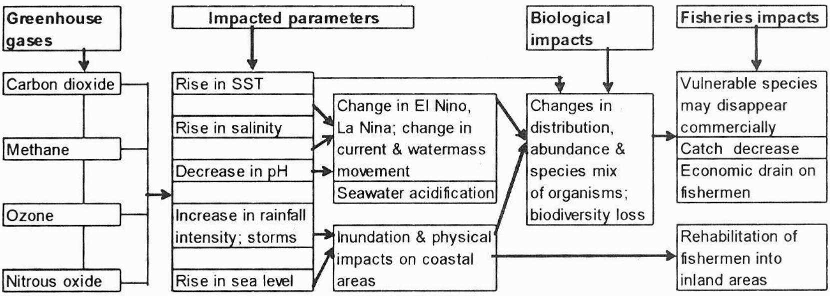

Fig : Schematic presentation of climate change on marine fisheries

Preliminary analysis indicates that the distribution of fish species with more rapid turnover of generations may show the most rapid demographic responses to temperature changes. The distribution of the oil sardine *Sardinella longiceps*, for instance, has responded markedly to increase in sea temperature. With the northern latitudes becoming warmer, the oil sardine, which is essentially a tropical species, is able to establish itself in the new territories and contribute to the fisheries along the northwest and northeast coasts of India.

Climate change and spawning of marine fisheries

The strategies adopted by other fish groups are also becoming evident. Some pelagic species such as the Indian mackerel *Rastrelliger kanagurta* show shift in the depth of distribution and are now caught by bottom trawlers. Demersal species such as threadfin bream *Nemipterus japonicus* appear to shift the month of peak spawning toward colder months off Chennai. There are also indications, which show that copepod abundance is shifting toward colder months off Mangalore. These findings indicate that the adaptable species may be able to adjust to the immediate challenge of rise in temperature for a shorter or longer duration.

Sea surface temperature and corals

The vulnerable groups such as the corals are in peril. It is found that extensive coral bleaching occurred in Gulf of Mannar and Andaman and Lakshadweep Seas when the SST was 31° C or more in 1998 and 2002. The intensity of bleaching was directly related to the number of days the higher temperature prevailed.

Climate change and sea level

The effects of climate change on fisheries will affect the fisheries sector that is already characterized by stagnating catches, full utilization of resources, large overcapacity and conflicts among fishers. The existing craft and gear combinations may have to be modified due to changes in resource composition. Due to sea level rise and inundation, the coastal fishing communities will be the worst affected. The mean sea level (MSL) has increased at the rate of 0.705 mm, 1.086 mm and 3.772 mm per year in the Arabian Sea, Bay of Bengal and Andaman Sea, respectively during 1992-2005.

It is much more difficult to project how populations will behave under radically different conditions. Under these conditions, fisheries stock assessment, already difficult, may prove impossible. Fisheries management will likely become far more contentious because the abundance of fish populations and the composition of communities will change in unexpected ways. Projections on future scenarios of the impacts, building awareness, preparedness, and planning and implementing the mitigation measures should start now so that the insidious changes are anticipated and addressed.

The initial results emphasize the need for finding answers to several questions. What will be the influence of rising seawater temperature on the bombay duck, whose northern boundary is landlocked? The distribution and migration of oceanic tunas, which are influenced by thermocline, may be strongly influenced. The sex of sea turtles is critically determined by the soil temperature at which the embryo develops. Temperature above 28° C produces only females. How the turtles would adopt to this crisis? Will there be species succession of phytoplankton with the domination of temperature tolerant species? Is the massive intrusion of pufferfish and medusae into the Indian coastal waters in recent years a fall out of climate change?

Suggested Readings

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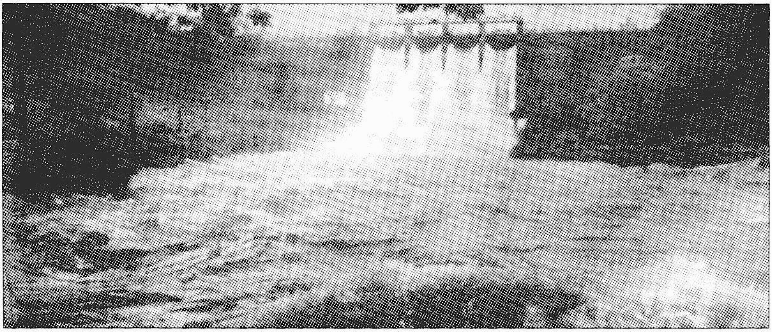

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