Coconut Phenology and Yield Response to Climate Variability and Change

Krishna Kumar K. N.

Thesis submitted in partial fulfilment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

in

ATMOSPHERIC SCIENCE

under the

Faculty of Marine Sciences

Department of Atmospheric Sciences
COCHIN UNIVERSITY OF SCIENCE AND TECHNOLOGY
KOCHI, INDIA

October 2011

DECLARATION

I hereby declare that the thesis entitled, **"Coconut Phenology and Yield Response to Climate Variability and Change"** is an authentic record of research work carried out by me under the supervision and guidance of Dr. G. S. L. H. V. Prasada Rao, Professor of Agricultural Meteorology, Academy of Climate Change Education and Research, Kerala Agricultural University and Dr. H. S. Ram Mohan, Professor of Meteorology (Retired), Department of Atmospheric Sciences, Cochin University of Science and Technology, in partial fulfilment of the requirements for the award of the Ph.D. degree in the Faculty of Marine Sciences and no part thereof has been presented for the award of any other degree in any University / Institute.

Krishna Kumar K. N.

Kochi - 16
10.10.2011

CERTIFICATE

This is to certify that this thesis titled, **"Coconut Phenology and Yield Response to Climate Variability and Change"** is an authentic record of the research work carried out by Mr. Krishna Kumar K. N, under my supervision and guidance at the Department of Atmospheric Sciences, Cochin University of Science and Technology, in partial fulfilment of the requirements for the Ph.D. degree of Cochin University of Science and Technology under the Faculty of Marine Sciences and no part thereof has been presented for the award of any degree in any university.

Dr. H. S. Ram Mohan
Supervising Co - Guide
Professor (Retired)
Department of Atmospheric Sciences
Kochi-682016

Dr. G. S. L. H. V. Prasada Rao
Supervising Guide
Associate Director of Research
Kerala Agricultural University
Thrissur-680656

Kochi - 16
10.10.2011

ACKNOWLEDGEMENTS

First and foremost, I would like to express my deep and sincere gratitude to my research supervisor Dr. G. S. L. H. V. Prasada Rao, Associate Director of Research and Professor of Agricultural Meteorology, Kerala Agricultural University, Vellanikkara, Thrissur for his always insightful suggestions and expert guidance. His unwavering commitment to his students and constant demand for excellence really helped me bring this work to fruition. Above all and the most needed, he provided me unflinching encouragement and support in various ways. Secondly, I would like to record my gratitude to Dr. H. S. Ram Mohan, Professor of Meteorology (Retired), Cochin University of Science and Technology, Kochi for his constructive guidance, generous support and inspired suggestions as well as giving me extraordinary experiences through out the work. Without his guidance as a great mentor, this work would not have been possible. I would like to express my gratitude to AICRP on Agrometeorology, CRIDA (ICAR), Hyderabad for providing financial support that made this research possible. I am grateful to the Special Officer, Academy of Climate Change Education and Research, Kerala Agricultural University, Vellankikkara, Thrissur for providing the excellent computing facilities through out the Course of study. I wish to express my warm and sincere thanks to Dr. Santosh K. R, Head, Department of Atmospheric Sciences, Cochin University of Science and Technology and my Doctoral Committee Member for providing necessary facilities at DAS, CUSAT during the course of my doctoral work.

I owe my deepest gratitude to Dr. A. V. R. Kesava Rao, Scientist, ICRISAT, Hyderabad who has extended technical support and encouragement. I am highly indebted to Dr. C. A. Babu, Professor, DAS, CUSAT for inspiration and valuable suggestions for shaping the research work. I would also acknowledge Dr. Venu G. Nair, Lecturer, DAS, for his wholehearted support and necessary help during the study period. My warm thanks are due to Mr. N. Manikandan, Research Associate, Agromet Data Bank, CRIDA, Hyderabad for providing me necessary help for the study. My thanks are also due to Mr. Unnikrishnan Thekkepat who has rendered assistance in statistical analysis. Furthermore, I would like to thank Dr. B. Ajithkumar and Smt. Lincy Davies, Assistant Professors, Department of Agricultural Meteorology, Kerala Agricultural University for their encouragement and help. My special thanks go to Mr. C. S. Gopakumar and Mr. P. Sajeesh Jan, Assistant professor, Kerala Agricultural University for valuable discussion during course of research work.

I convey special acknowledgement to all my Departmental Staff members at the Academy of Climate Change Education and Research, Kerala Agricultural University. Sri. P. M. Paulose, Sri. V. N. Gopi, Mr. T. P. Gangadharan, Ms. V.P. Mini Sathish, Ms. Dhivya Sajith, Mr. T. V. Saju, Mr. P. R Sunil, Mr. M. A. K. Azad and Ms. Leelamani, have helped me in many ways for the successful completion of this endeavour. The office and the technical staff at the DAS, CUSAT rendered me all their support and help during the course of this work. I would like to express my deep sense of gratitude to all of them.

I devote my deepest gratitude to my parents for their unlimited love and support. They have encouraged me throughout the years of my study.

Lastly, I offer my regards and blessings to all of those who supported me in any respect during the completion of this thesis

Krishna Kumar K. N.

CONTENTS

LIST OF TABLES

LIST OF PLATES

LIST OF FIGURES

Chapter I

Introduction

The Coconut palm, also known as the *Cocos Nucifera.* **L** is one of the most fascinating and beautiful palms in the world. Epigraphical, literary and sculptural evidence provide proof that coconut has served humanity for more than three millennia. The palm is looked upon with reverence and affection and is referred to by such eulogistic epithets as “Kalpavriksha”, tree of heaven, the tree of abundance, nature’s super market, king of palms and the tree of life. The coconut is believed to have originated in Southeast Asia (Indonesia, Malaysia, Philippines) or Micronesia (Harries, 1977; Purseglove, 1968 and 1972). Coconut has been cultivated in India since ages and plays an important role in social, economic and cultural activities of the people. The palm is amenable to both plantation and homestead management and it can be either a major crop or a minor one in a homestead garden of mixed crops. While responding favourably to scientific management, the palm also tolerates negligent farming to a certain extent. Thus, it can adapt to the divergent farming situations and management practices that are prevalent in different agro-climatic regions.

The coconut palm is usually found near the sea on sandy beaches where it can tolerate salt spray and brackish soils. It is also grown under different soil types such as loamy, laterite, coastal sandy, alluvial, clayey and reclaimed soils of the marshy low lands. The ideal soil conditions for better growth and performance of the palm are proper drainage, good water-holding capacity, and presence of water table within three metres and absence of rock or any hard substratum within two meters of the surface. The coconut palm can also grow well inland, within altitudinal limit of 600 m to 1752 m in the tropics. It requires an equatorial climate with high humidity. A year-round warm and humid climate favour the growth of coconut. The ideal mean annual temperature, which can be tolerated by coconut palm, is around 27ºC with 5-7ºC diurnal variation. The palm does not withstand prolonged spells of extreme weather/climate variations. A well-distributed rainfall of 1300-2300 mm per annum is preferred. It is known as a coastal tree since it is grown along the Coasts and islands and does not tolerate high temperature range, that is the difference between the maximum and minimum temperatures.

The Coconut palm tree (*Cocos Nucifera*. **L**) is grown widely in the tropical areas around the world. It is found in Asia, Central and South America and Africa. Coconut is grown in more than 86 countries worldwide, with a total production of 61 billion nuts per annum (Asian-Pacific Coconut Community, 2010). In the Asian continent, it grows well in Indonesia, Malaysia, India, Philippines, Thailand, Sri Lanka, Burma and Cambodia (Fig. 1.1).

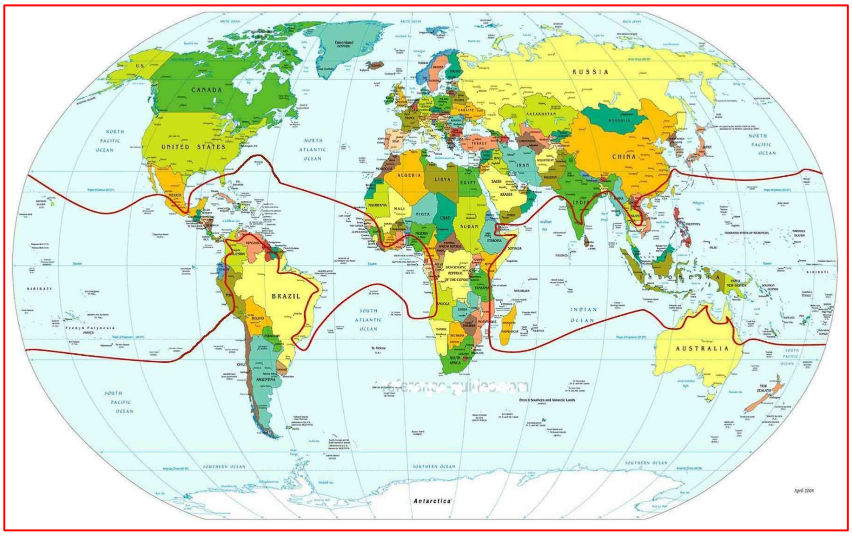


Fig. 1.1: Natural habitat of coconut

In Africa, this palm thrives in Nigeria, Kenya, Tanzania, Ghana, Mozambique and Madagascar. In North and South America, coconut palms grow in abundance in Florida, Hawaii, the Caribbean, Brazil, Mexico and Venezuela. However, Indonesia, India, Philippines and Sri Lanka play a major role contributing 76.1% of the world's coconut production (Table 1.1). In terms of coconut productivity, India ranks first (7748 nuts/ha), followed by Sri Lanka (7365 nuts/ha). The least productivity is seen in Solomon Islands (1695 nuts/ha) and Samoa (1935 nuts/ha).

Table 1.1: Area and production of coconut in the different coconut growing countries of the world (2008)

Country	Area		Production		Yield
	`000 hectares	Share (%)	' 000 nuts	Share (%)	(nuts/ha)
Federated states of Micronesia	17	0.1	40000	0.1	2353
Fiji	60	0.5	150000	0.2	2500
India	1903	15.6	14744000	24.1	7748
Indonesia	3799	31.2	16235000	26.6	4273
Kirribati	29	0.2	131300	0.2	4528
Malaysia	115	0.9	390000	0.6	3391
Martial Islands	8	0.1	30300	0.0	3788
Papua new guinea	221	1.8	1101000	1.8	4982
Philippines	3380	27.8	12573000	20.6	3720
Samoa	93	0.8	180000	0.3	1935
Solomon Islands	59	0.5	100000	0.2	1695
Sri Lanka	395	3.2	2909000	4.8	7365
Thailand	247	2.0	1186000	1.9	4802
Vanuatu	96	0.8	307700	0.5	3205
Vietnam	141	1.2	760080	1.2	5391
Other Asian Countries	351	2.9	1043118	1.7	2972
Other Pacific Countries	104	0.9	374910	0.6	3605
Other African Countries	641	5.3	2108150	3.5	3289
Other American Countries	505	4.2	6716824	11.0	1330
Total world	12164	100	61080382	100.0	5021

1.1 GLOBAL COCONUT POSITION

There has been tremendous expansion in area and production of coconut in the world during the last four decades. The world coconut production has grown steadily over the period, at an estimated annual rate of 2 per cent, with production accelerating in the last twenty years: the trend growth rate from 1985 to 2009 was 2.1 per cent per annum, compared to 1.5 per cent for the period from 1961 to 1985. The production also showed a steady increase in trend during the decade under reference (Fig.1.2).

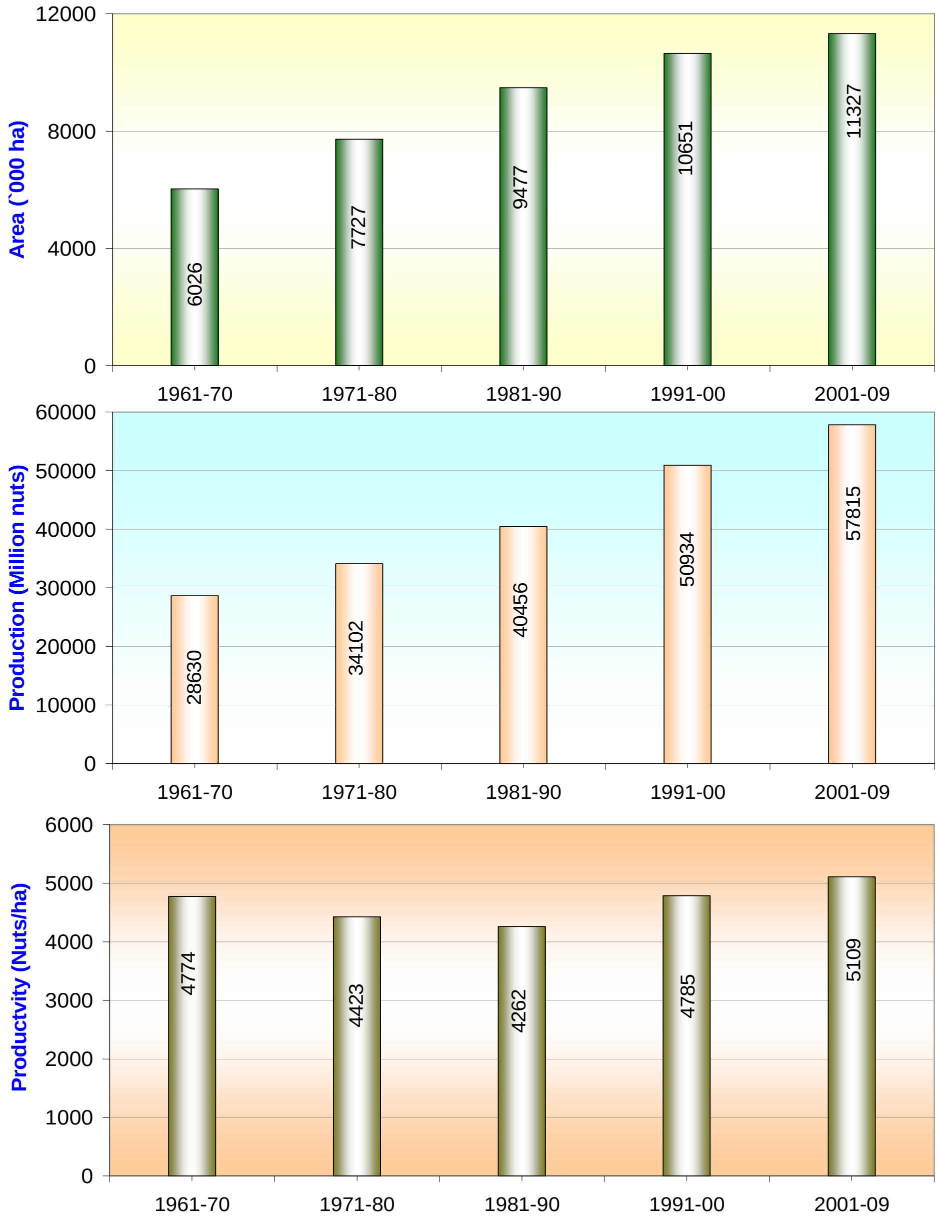


Fig. 1.2: Decade - wise world coconut area, production and productivity from 1961 to 2009

However, during the period between 1971 and 1990, there was a declining trend in productivity in spite of area expansion and steady increase in coconut production. There was an increase of 131.3 per cent in area and 130.4 per cent in production while increase in the productivity was not in tune with the area and production. In fact, there was a negative trend (0.5%) in coconut productivity due to low productivity between 1970 and 1990.

1.2 COCONUT POSITION IN INDIA

India occupies the second position in the world with an annual production of 15 billion nuts. Our country with 15.6 % of coconut cultivation land contributes to 24.1 % of coconut production at the global level. There are about 5 million coconut holdings in the country with 98 per cent of such holdings occupying below two hectares. The coconut palm is grown in many diverse agro climatic zones of India, except sub tropic and temperate regions. However, they are favourably adapted to the coastal agro Ecosystem coastline of 8129 km and its Peninsular region bounded by the Arabian sea on the West, the Bay of Bengal on the East and Indian ocean on the South. Andaman and Nicobar Islands in the Bay of Bengal and Lakshadweep Islands in the Arabian Sea are unique inland eco-systems where coconut plantation is widely grown. The major coconut growing States are depicted in Fig 1.3. The four southern States put together account for 90.99% of the total coconut production in the country (Kerala 36.89%, Tamil Nadu 34.11%, Karnataka 13.83%, Andhra Pradesh 6.17% and other States 9.01%). Among the major coconut growing states, Tamil Nadu has the highest productivity (13771 nuts/ha). Tamil Nadu ranks first with regards to the expansion of area and production. Higher productivity in Tamil Nadu can be attributed to big size of coconut farms under irrigated conditions and better management practices on commercial scale.

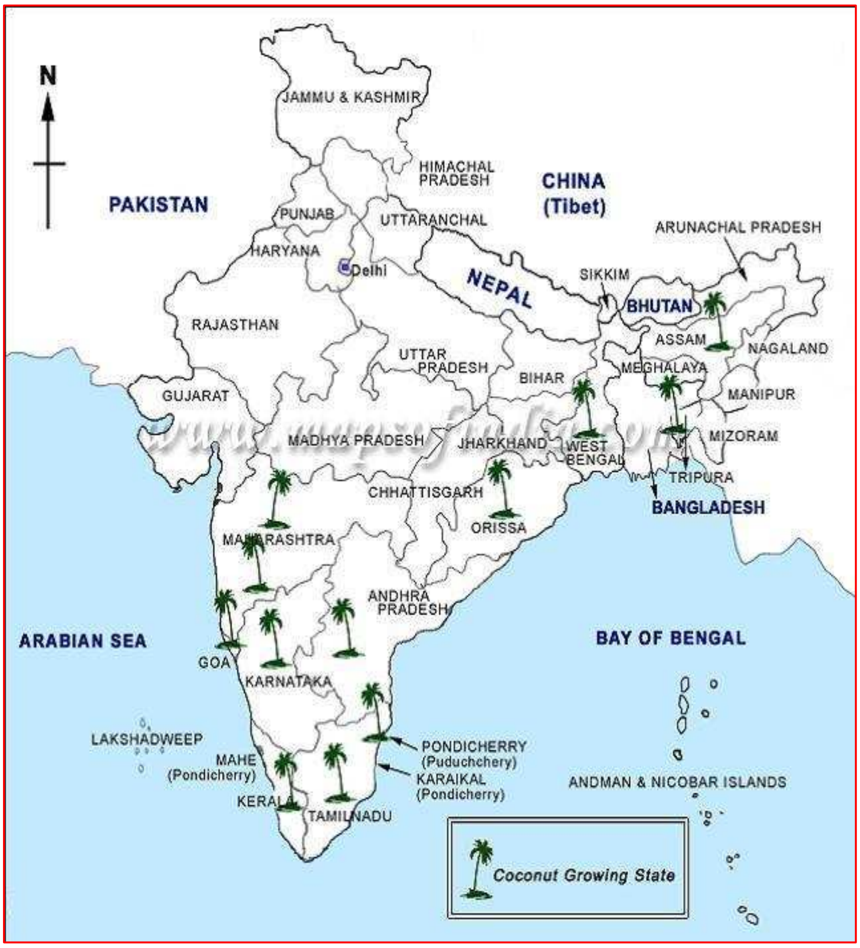


Fig. 1.3: Major coconut growing States in India

While Kerala accounts for the largest production of coconut in the country, productivity of coconut in Kerala is 7365 nuts/ha, even below the All India yield of 8303 nuts/ha achieved in 2008-09 (Table 1.2). The other coconut producing States in the country include Assam, Goa, Gujarat, Maharashtra, Orissa, Tripura, West Bengal, Andaman & Nicobar Islands, Lakshadweep, Puducherry and Nagaland. Productivity-wise, some of these states, viz., Maharashtra (8338 nuts/ha), West Bengal (12430 nuts/ha), Lakshadweep (19630 nuts/ha) and Puducherry (14619 nuts/ha) performed better than some of the major producing States.

Table 1.2: Area, production and productivity of coconut in India 2008-09

States/Union territories	Area		Production		Yield (Nuts/ha)
	In 1000 ha	Percentage share (%)	Million nuts	Percentage share (%)	
Andhra Pradesh	104.00	5.49	970.00	6.17	9327
Assam	18.80	0.99	147.10	0.94	7824
Goa	25.61	1.35	128.18	0.81	5005
Gujarat	15.98	0.84	157.42	1.00	9851
Karnataka	419.00	22.12	2176.00	13.83	5193
Kerala	787.77	41.58	5802.00	36.89	7365
Maharashtra	21.00	1.11	175.10	1.11	8338
Nagaland	0.92	0.05	0.55	0.00	598
Orissa	51.00	2.69	275.80	1.75	5408
Tamil Nadu	389.60	20.56	5365.00	34.11	13771
Tripura	5.80	0.31	11.40	0.07	1966
West Bengal	28.60	1.51	355.50	2.26	12430
Andaman and Nicobar Islands	21.69	1.14	82.00	0.52	3781
Lakshadweep	2.70	0.14	53.00	0.34	19630
Pondicherry	2.10	0.11	30.70	0.20	14619
All India	1894.57	100.00	15729.75	100.00	8303

1.3 COCONUT POSITION IN KERALA

Kerala State is located between 8°15` N and 12°50`N latitudes and between 74°50`E and 77°30`E longitudes (Fig. 1.4). The State of Kerala is popularly known as the "Gateway of monsoon" over India. It is a strip of land running almost in North - South direction and is situated between the West Arabian sea on the West and the ranges of Western Ghats and Nilgiri hills on the East both running parallel to each other. From the Western Ghats, the State undulates to the West and presents a series of hills and valleys intersected by numerous rivers. On extreme West, the State is more or less flat. These characteristics demarcate the State into three natural regions viz., the eastern high lands, the hilly midlands and western low lands. The changes in the geographical and topographical features due to man - made interventions are likely to influence atmospheric circulation altitudinally to a large extent. It may be one of the reasons in recent times for uncertainties in monsoon variability and rainfall distribution over Kerala. Kerala is blessed with tropical rain forests, rich biodiversity and has many rivers and streams and is spread in 13 natural agro-ecological zones. Agricultural production in Kerala is still dependent on weather and climate despite the impressive advances in agricultural technology over the last half a century. In fact, Kerala ranks low among several Indian States in productivity of major crops. Moreover, agrometeorological services have become essential because of the many challenges faced by agricultural production due to increasing climate variability and climate change.

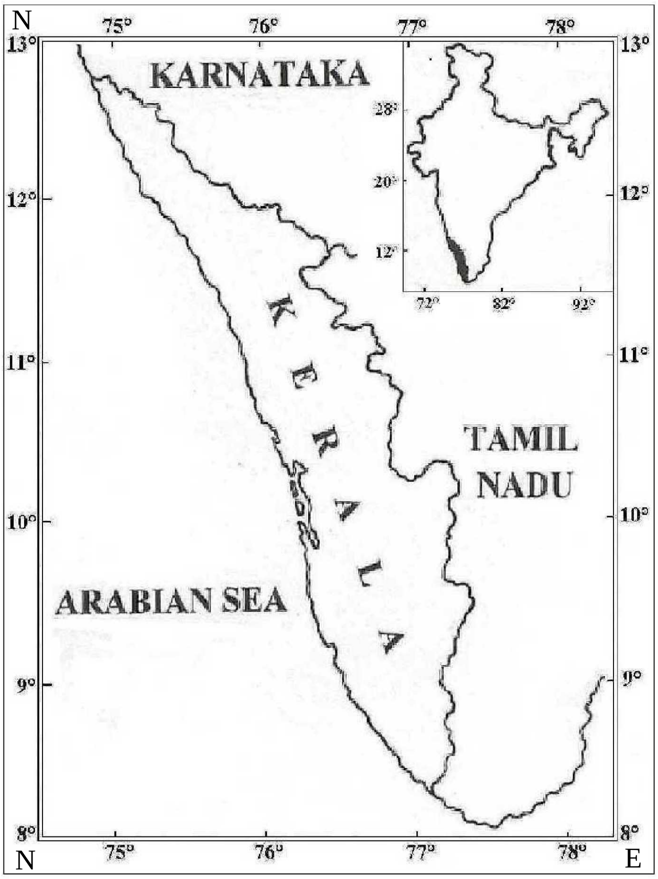


Fig. 1.4: Location map of Kerala

With coverage of 8.2 lakh ha, coconut occupies 38 per cent of the net cropped area and provides livelihood to over 3.5 million families in Kerala. The productivity levels in Kerala are lower than other major producing states. Unlike other commercial crops grown in the country, coconut is essentially a small holder's crop. It is grown mostly in homestead gardens with small holdings under rainfed conditions. In Kerala State alone, there are about 2.5 million holdings. Among the 14 districts in Kerala, Kozhikode ranked first (851 million nuts), followed by Malappuram (832 million nuts) and Thrissur (575 million nuts) in terms of coconut production. In the case of productivity, Malappuram (7944 nuts/ha) stood first followed by Thiruvananthapuram (7755 nuts/ha) and Thrissur (7038 nuts/ha). Kozhikode, Malappuram and Kannur districts share 38 per cent of the coconut area (Table 1.3).

Table 1.3: Area, production and productivity of coconut in Kerala 2007-08

Districts	Area (in hectares)	Percentage share	Production (in million nuts)	Percentage share	Productivity (nuts/ha)
Thiruvanathapuram	72473	8.85	562	9.96	7755
Kollam	58575	7.15	378	6.70	6453
Pathanamthitta	17903	2.19	107	1.90	5977
Alappuzha	43976	5.37	301	5.34	6845
Kottayam	35226	4.30	205	3.63	5820
Idukki	19925	2.43	72	1.28	3614
Earnakulam	49412	6.03	292	5.18	5909
Thrissur	81697	9.98	575	10.19	7038
Palakkad	60393	7.38	422	7.48	6988
Malappuram	104731	12.79	832	14.75	7944
Kozhikode	122929	15.01	851	15.09	6923
Waynad	12292	1.50	45	0.80	3661
Kannur	82223	10.04	554	8.82	6738
Kasaragod	57057	6.97	445	7.89	7799
Kerala State	818812	100.00	5641	100.00	6889

But it is interesting to observe that despite the incidence of the dreaded disease (root wilt) in the southern districts of Kollam, Alappuzha, Kottayam, Ernakulam, Idukki and Thrissur, the per palm productivity in these districts has been consistently on par with that of the disease free northern districts of Malappuram, Kozhikode, Kannur and Palakkad. It could be attributed to uniform distribution of rainfall towards the South when compared to that of northern districts of Kerala. Low productivity in Kerala is attributed to several factors, viz., high rainfall during monsoon. insignificant rainfall in several parts of Kerala during summer months, lack of irrigation during summer, poor nutrient status of soils, lack of agronomic practices, prevalence of dreaded root wilt disease in the problem zone of Kerala, incidence of stem bleeding in northern zone, of late attack of coconut mite and bud rot and the farmers` reluctance in application of fertilizers due to uneconomic price offered to coconut growers. In addition, it is mostly grown under rainfed conditions. The seasonal and annual variations in coconut production is mainly attributed due to dry spells within the monsoon and soil moisture deficiency from December to May, if pre - monsoon showers fail, which is not uncommon in the humid tropics under rainfed conditions. The severity of soil moisture deficiency is more towards northern districts of Kerala due to uni- modal high rainfall, followed by prolonged dry spell for four to six months. Of course, the soil moisture status depends not only on soil type but also on topography, which is a significant feature in Kerala as coconut cultivation is seen in low land, mid land and high lands. The decline in coconut production in Kerala during 1983 - 84 was 18% due to disastrous drought during summer 1983 and 7.1% in 2002-03 depending upon the severity of the soil moisture stress (Fig. 1.5). Summer drought during 2004 also adversely affected coconut yield to some extent over Kerala.

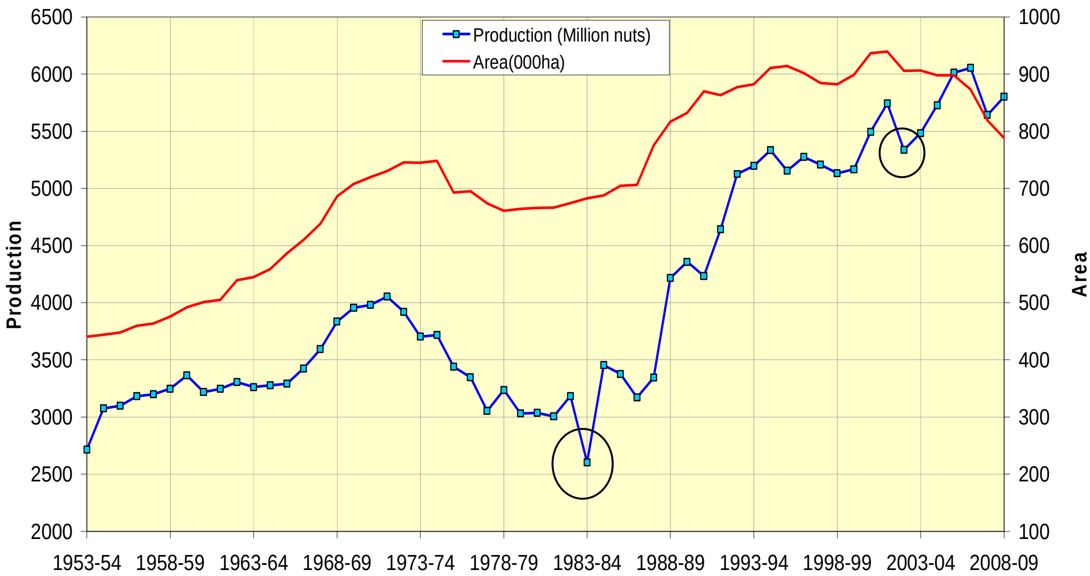


Fig. 1.5: Coconut area and production (million nuts) in Kerala from 1949 - 50 to 2008-09

1.4 INSPIRATION FOR PRESENT STUDY

Salter and Goode (1967) in their review sum up the position with regard to coconut by stating that "with so great a time lapse between the initiation of leaf and inflorescences primordia and flowering and with many other inflorescences in various stages of development present at the same time, it has been found difficult to relate accurately growth, flowering or yield responses to any particular climatic condition." The present investigations are to elucidate the response of various biotic events like the leaf and spadix characters of coconut to seasonal and weather aberrations. In the case of coconut, there exists a long reproductive phase of three-and-a-half years from primordium initiation to nut harvest in coconut. And at any point of time, all the growth, development and reproductive characters like functional leaves, inflorescence, spathe and spadix openings, button shedding, tender nuts and ripened nuts are noticed in coconut.

In view of the long duration (44 months) between the primordium initiation to nut maturity, the occurrence of dry spell or wet spell in any season/year would affect the yield for the subsequent three to four years. Rajagopal *et al.,* (1996) observed that the nut production under rainfed condition is influenced significantly by the length of dry spells at critical stages and the dry spell during the primordium, ovary development and button size is crucial for the production of nut yield. It is also reported that nut production can be sustained at relatively high by giving life saving irrigation during the summer months. Kumar *et al.*, (2007) reported that longer dry spell affects the nut yield for next four years to follow with stronger impact on fourth year, irrespective of the total rainfall. Since coconut has long reproductive phase, it is a complex phenomenon to assess the critical stages which are affected due to soil moisture stress or excess under field conditions. Therefore, there is a need to understand the interactions between the occurrence of dry spells/wet spells and their effects on various development stages of coconut under the rainfed conditions.

In order to study the leaf and spadix phenology of coconut, evolution and development of the leaf, inflorescence and female flowers during different seasons of the year have to be traced. The effect of seasonal factors on the yield of perennial crop like coconut cannot be easily assessed unlike in the case of annual crops. In annual crops, the effect is manifested immediately or during course of the year while in the case of perennial crop like coconut, the effect on floral and yield characters is discernible only after some time lag. The effect of a particular season on phenological characters of coconut may be noticed in the same season or following season due to prolonged reproductive phase. At present, the information on the above aspects is seen in the literature mainly based on the data generated between 1920s and 1960s from the northern zone of Kerala. The work was mainly based on the coconut grown at Pilicode, Nileshwar and Kasaragod (formally known as Nileshwar I, II and III), having various soil types along the West Coast with marine climate dominating in Kasaragod district of Kerala. Probably the response of coconut may be different if the data on biotic events of leaf and spadix phenology of coconut is generated systematically in varied climates and studied in detail. To understand the phenology of coconut, systematic weekly observations on various biotic events of coconut for longer periods are required, say for a period of at least five years. Therefore, a field experiment was undertaken under AICRP on Agrometeorology from February 2002 to June 2007. The experimental site was located in Seed Production - Cum-Demonstration Farm, Coconut Development Board, Vellanikkara (10^0 31'N and 74^0 13'E). Presently, it is under the control of Central Nursery, Kerala Agricultural University, Vellanikkara. The information generated on coconut phenology could probably be used in crop improvement and management programmes.

As mentioned in the preceding paragraphs, coconut production is vulnerable to weather vagaries such as floods and droughts. The effect of drought is much more felt where the coconut gardens are grown under rainfed conditions. Also, there is a lag period between the seasonal effects and final coconut production since coconut has a long reproductive phase. The coconut gardens experience prolonged dry spells or droughts during the summer if rain fails during the northeast monsoon period. The failure of northeast monsoon is not uncommon in northern districts of Kerala, which will adversely affect the coconut production to a large extent. As reported, the frequency of occurrence of such weather events like floods and droughts are not uncommon under the projected climate change scenario. Therefore, there is need to understand not only the phenology of crop but also the yield pattern with reference to climate variability and change under rainfed conditions. Keeping the above aspects in view, the present study was taken up with the following objectives.

1.5 OBJECTIVES

- To study the seasonal and weather effects on biotic events of coconut
- To examine the phenological phases which influence the coconut yield
- To study the effect of droughts on coconut yield
- To study the impact of climate variability and change on coconut production and productivity
- To develop models for predicting coconut production in the State of Kerala

The information generated on coconut phenology could be used in crop improvement and management programmes for the benefit of the coconut farmers of Kerala. This is the first attempt to understand the effects of climate variability and change on coconut productivity under field conditions. The models developed can be used for estimating coconut production in the State of Kerala. This will help in formulation an appropriate export import (EXIM) policy of coconut and market regularization for the benefit of coconut producers and consumers.

Chapter II
Review of literature

The reproductive phase of coconut takes about 44 months, starting from primordium initiation to harvest unlike other perennial crops. Aberrations in weather during the development process of spathe will affect the final nut size, yield and oil content. Among the weather variables, air temperature (maximum and minimum), rainfall, rainy days, relative humidity, vapour pressure deficit, wind speed and sunshine hours are found to have direct effect on the crop growth and yield. Though the literature on crop weather relationships of coconut is scarce, studies on the effect of rainfall on crop yield have been attempted by several workers in and outside India. It is also an established fact that rainfall distribution alone can determine the yield to a greater extent. In this chapter, the literature available on crop weather relationship and phenology of coconut has been briefly reviewed.

Abeywardena (1955) reported that weather parameters of different months of an year did not contribute to the yield of next successive years production to the same degree because in the cycle of development of bunches, there are certain periods (phases) which are extremely susceptible to weather. Marar and Pandalai (1957) in a study opined that it was not possible to explain the influence of seasonal changes in terms of individual weather parameters. Nambiar *et al.,* (1969) distinguished three distinct phases of fruit development. The first phase of slow progressive growth is for about three months after fertilization, followed by the next phase of rapid growth for about four months and finally the rapid decline in growth rate in about two months. They observed that the rate of growth during the second phase of development is highly correlated with the final volume and weight of unhusked nut and copra content. Any weather aberration coinciding with active period of development will adversely affect the rate of growth and final size of the nut and copra content. Rao and Nair (1986) observed a negative relationship between heat units (which is a function of temperature) during the second phase of development (4-7 months after fertilization) and husked nut weight. There was a marked decline in nut size from July to December in response to an increase in total heat units, indicating that the total heat units above 2100 day° C were not congenial for nut development. According to Abeywardena (1971), the yield variations due to weather factors are more pronounced in coconut than in other tree crops, the reason being the long reproductive cycle of coconut obviate from vagaries of weather in its external manifestations. Bai *et al.*, (1988) in their study on effect of weather variables on stress development in coconut showed that when the palms were exposed to environmental situation wherein the radiation was around 265 W/m^2, temperature 33°C and VPD 26 m bars, the stomatal closure set in. Thus the significance of both soil moisture level and agrometeorological parameters on stress in coconut has been understood.

Nair and Unnithan (1988) studied the influence of seasonal climatic factors on coconut yield in different lag periods. The most important climatic factors influencing the annual yield of coconut were sunshine hours, evaporation and relative humidity. Sunshine hours and evaporation showed a positive correlation with yield while relative humidity showed a negative correlation. Rainfall and number of rainy days did not shed much light on the pattern of influence. Vijayakumar *et al.,* (1988) in a study of the relationship between 11 weather variables and coconut yields, identified 7 lag periods, which corresponds to various growth stages. Among the variables selected, rainfall had positive influence consecutively on five of the seven lag periods, while temperature and relative humidity had their influence on two or three lag periods. Peiris *et al.,* (1995) showed that past studies on the agroclimatological aspects of coconut have not been addressed adequately and were not able to explain the yield variation between and within years. This is mainly due to the perennial nature of these crops having a prolonged reproductive phase of 44 months (From the initiation of the inflorescence primordium to full maturity of the nuts). The effect of climate and weather is evident at all stages of the development cycle and this affects the production of nuts. Further, the analyses of the effect of climate on yield are complicated by the high variability of, and interrelationship between, the climate variables.

2.1 EFFECTS OF WEATHER ELEMENTS ON COCONUT

2.1.1 Rainfall

Copeland (1931) reported that a mature coconut palm loses as much as 6-16 gallons of water daily by transpiration. It was also reported that it is the distribution pattern of which is more important than the quantum of rainfall. Park (1934) observed that a severe drought lasting for 8 months affected the coconut palm even two years later after the cessation of drought period. Patel and Anandan (1936) pointed out that yield in particular year was influenced by the January to April rain during the years of harvest and preceeding two years. In another study, Patel (1938) observed that primordia of inflorescence get aborted due to drought in Kasaragod. Menon and Pandalai (1958) noticed that a period of drought occurring 15-16 months before opening of inflorescence leads to abortion of spadices. Abeywardena (1968) observed a harmful effect of heavy rainfall during southwest monsoon (Sri Lanka) causing high relative humidity, low temperature and low insolation. He observed that coconuts are more moisture sensitive in the period from May to August than in the rest of the periods. It assumed a wide variation in moisture sensitivity in the other two periods. From January to April no harmful effect due to heavy rainfall was observed, whereas in the period from September to December it clearly indicated that any rainfall in excess of 355mm/month was extremely harmful to the crop as temperature is low and humidity is high.

Cooman (1975) observed a negative correlation between fruit set and accumulated water deficit over 5 months, one year earlier. He concluded that influence of water availability period on fruit set was the highest in the period between the appearance of the flower primordia and the ovary differentiation. Rao (1982) attempted to find out a relationship between the annual coconut yield and rainfall trend in Pilicode region of the northern Kerala using twenty years moving average. The study indicated that high rainfall during monsoon as well as the absence of pre and post monsoon showers adversely affected the subsequent years` coconut yield. Beyond a certain maximum rainfall, the precipitation may not be useful and increase in yield may not be manifested in coconut according to Thampan (1982). Vijayaraghavan *et al.,* (1988) were of the opinion that very high rainfall interferes with pollination thus affecting the nut yield. Varghese and Kunju (1988) reiterate the fact that monsoon rainfall and the first and third annual nut yields exhibit significant positive correlation in the backwater areas of Kuttanad.

Rainfall during March and May three year prior to harvest of coconut had a positive contribution to yield, whereas rainfall during January and November had a significant negative influence. As such, the monthly rainfall during the rest of the months was found to have no significant influence on coconut productivity (Babu *et al.*, 1993). In the dry intermediate zone, Peiris (1993) observed the influence of rainfall in two monthly sub periods in the year prior to harvest on the coconut. The most influential period is January and February and least influential period is July to August. The rainfall during May - June has a depressing effect and rainfall in excess of 450 mm was not utilized by the palm. High rainfall during September/ October has discernible effect while high rainfall during October/November showed significant effect to the palm. Rajagopal *et al.*, 1996 studied the impact of dry spells on the ontogeny of coconut fruits and its relation to yield. The study indicated that the coconut production under rainfed conditions is influenced significantly by the length of dry spells at critical stages and the availability of adequate moisture in the field on primordial initiation, ovary development and button size nut in that order are most crucial for the production nuts.

2.1.2 Temperature

This is another important factor, which has profound influence on the distribution and performance of coconut palm. Infact it is temperature that sets a limit to the latitude and of altitude up to which coconut can be successfully cultivated. The coconut palm likes equable temperature of neither very hot nor very cold. The optimum mean annual temperature for best growth and maximum yield was found around 26-27°C and with a diurnal variation of 7-8°C (Marar and Pandalai, 1958). According to Child (1964), the ideal mean annual temperature is usually put at around 27°C, and the average diurnal variation between 5° C and 7 °C. Low temperature seemed to be more limiting than high temperature. Louis and Annappan (1980) obtained a negative correlation of the yield with temperature and relative humidity. Thampan (1981) found that yield of coconut was reduced if the average minimum temperature was below 21^0C. Vijayaraghavan (1988) reported that mean minimum temperature during northeast monsoon in Tamil Nadu and winter season were low and very low respectively. The nut yield was also low and very low during the above seasons. Between the southwest monsoon and summer season period when the minimum temperature was high (around 20^0C) the nut yield was higher during the above period.

2.1.3 Relative humidity

Relative humidity is one of the factors determining the transpiration rate and consequently the water and nutrient uptake by the palm. Even in the case of sufficient water supply from the soil, low ambient relative humidity may induce stomatal closure in the palm thereby reducing its photosynthetic capacity. Copeland (1931) observed that relative humidity obviously related to rainfall, temperature and insolation should be such as to permit the most active transpiration with the palm suffering from loss of water. He had established that cloudiness arrests rate of transpiration considerably. According to him the prevalence of high humid conditions throughout are not favourable for the palm. He opined that humidity reduces transpiration and thereby reduces the uptake of nutrients. Marar and Pandalai (1957) cited that coconut palm likes a warm humid climate. High temperature and high relative humidity perhaps have an intense effect on the pollination system of the coconut palm (Louis and Annappan, 1980). In general, the relative humidity and temperature played an important role during the ontogeny of inflorescence and nut development in coconut (Kumar, 2009).

2.1.4 Insolation

Sunshine is another important weather factor affecting the biological function and photosynthetic activity of the plants. Copeland (1931) made an extensive observation on the effect of sunlight and transpiration, which influence the vital growth process in the plant. He established that cloudiness arrests the rate of transpiration considerably. Wickramasurya (1968) observed that spadix initiation and production of coconut in Sri Lanka are greater in March - September, when average day length is greater than during the rest of the year. Cooman (1975) observed a positive correlation between the rate of insolation 29 and 30 months before harvest and the female flowers produced. Rao *et al.,* (1995) reported that percentage decline in net radiation (around 30 per cent) was high during the southwest monsoon season when compared to summer. The potential photosynthesis may be reduced during the rainy season as the decline in solar radiation and net radiation was significant. De Wit (1965) has reported that there could be 50 per cent of reduction in potential photosynthesis when the light intensity gets reduced to only 20 per cent of the intensities on clear days in the tropical areas at 10° N.

2.1.5 Wind

According to Copeland (1931) the effects of wind on the coconut palm depend upon soil moisture condition. Strong winds are not desirable as they do considerable damage to coconut plantation. It is more so in the case of surface planting.

2.2 PHENOLOGY OF COCONUT

The effect of seasonal factors on the yield of perennial crop like coconut cannot be assessed unlike in the case of annual crop. In annual crops, the effect is manifested immediately or during the course of the year whereas in the case of perennial crops the effect on yield characters is discernible only after some time lag. The effect of a particular season noticed may be due to the delayed effect of earlier seasons. This is due to particular growth characters of the perennial crop. The evolution and development of inflorescence of the palm has been traced by Patel (1938). The primordium of the inflorescence is reported to develop in the leaf axils about 32 months before the opening of the inflorescence. The primordia of the branches of florescence develop in about 16 months and male and female flowers in about 11 and 12 months respectively before the opening of the inflorescence. The ovary is first differentiated about 6-7 months before the opening of the inflorescence. Seasonal factors prevailing during the developmental stages during the period of 32 months before the inflorescence opens do affect the yield of nut. Louis and Annappan (1980) revealed two allied factors one is that the inherent nature of the individual or group of palm for higher and lower yield of nuts remain constant, inspite of the uniform treatment received by all the palms. The factor is that all the palms are being influenced by the environmental factors irrespective of their potentiality to yield. The study showed that the number of nuts harvested per palm during April - May (second half summer) is significantly high and distinct while low during the first half of southwest monsoon (May-June).

2.2.1 Seasonal variations in functional leaves and leaf shedding

The rate of production of leaves is the lowest during summer and most rapid during September-October (Patel, 1938). Sampson (1923) states that the rate of leaf development slows down during the rainy season. It was also pointed out that more leaves fall from the tree during the rainy season than in the dry weather due to the moist atmospheric conditions, favouring the growth of the fungus *Pestalotia palmarum*. However, his observation was not in agreement with the observations made by Patel (1938) who observed that the shedding of leaves is the least in the southwest monsoon when compared to that of hot weather season. Also, the shedding of leaves varies from season to season depending upon locality. It was also pointed out that it is not possible to say whether the variation in seasonal leaf shedding is due to the differences in the age of palms or soil conditions. Marar and Pandalai (1957) reported that coconut leaves are produced at shorter interval during November to December than the other parts of the year and shedding of leaf was found influenced by season; being least in southwest monsoon season. Kutty and Gopalakrishnan (1991) reported that the morphological characters like number of leaves retained by the palm, length of leaves, length of petiole, number of leaflets per leaf and girth of stem at collar region had positive correlation with yield and it was also stated that the periodicity of leaf emergence computed in terms of number of days elapsed between two successive leaf emergence had a negative correlation with yield.

2.2.2 Spadix emergence

Patel (1938) reported that the opening of bunches is very low during October, November, December and January while high during March, April and May. The interval between the successive spadices appears to remain the same for the main seasons even in different years. It varied between 27.8 and 33.4 days between Kasaragod and Nileswar-I, respectively. This is mainly due to the fact that the trees at Nileswar-I are very young.

In coconut palms that come to normal bearing stage, every leaf axil will normally produce an inflorescence (spadix). Larger number of spadices are produced in the hot weather season than in the other seasons or the interval in days between the opening of successive spadices was the least in hot weather season when compared to other seasons Marar and Pandalai (1957). Menon and Pandalai (1958) observed that the production rate of spadices was dependent on the rate of production of leaves. About11-15% of total number of spadices produced during a year emerges during the month of March, April and May. Bhaskaran and Leela (1983) reported that spadix production was maximum during hot weather period in Tall x Dwarf and WCT. Production of spadices and female flowers in WCT x CDO hybrid was high during March-May and absent during October-December. Kalathiya and Sen (1991) observed that the nut yield was found significantly and positively correlated with number of spadix produced and duration of female phase whereas number of leaves produced and length of spadix exhibited significant positive correlation with number of spadices. It is, therefore, suggested that the number of leaves, spadix production, length of spadix and duration of female phase should be considered as selection criteria for nut yield improvement in coconut variety ‘Dwarf Green’. Sreelatha and Kumaran (1991) observed that the spadix emergence was observed to commence by early January and it gradually increased, reaching a peak in the middle of March with a total of 29 spadices in the population studied during the standard week from 12th to 18th March. Thereafter, the production decreased slowly and attained zero by the next October. Vanaja and Amma (2002) reported that maximum number of spadices and bunch production were noticed during summer months (March to May). While it was low during post monsoon period (October to December) in both Komadan and WCT.

2.2.3 Female flower production

Marechal (1928) reported that female flower production was high from November to March in dwarf palms in Fiji. The number of female flower production in different seasons may be due to the differences in the number of spadices opened during periods (Patel, 1938). Marar and Pandalai (1957) noted that number of female flowers in general, is more in the inflorescences that are produced in the hot weather than in other seasons of the year. Shylaraj *et al.*, (1991) observed that Komadan mother palms were found significantly superior in girth of stem, number of fronds, number of bunches per palm, number of female flowers per spadix, percentage of fruit set and annual nut yield per palm when compared to that of the West Coast Tall. Maximum number of female flowers was produced during the summer months (March-May) and minimum during winter (Rao, 1988). Vanaja and Amma (2002) reported that about 62 per cent of annual female flower production was observed during hot weather period (February to May). According to them, female flower production per spadix was found maximum from September to February and minimum from May to July in both Komadan and WCT. Ratnambal *et al*., (2003) noted that maximum number of female production in tall varieties was from April to June. Samanta *et a.l*, (2009) observed that the highest number of female flower production was during the month of May.

2.2.4 Seasonal variations in spathe emergence

Vijayaraghavan *et al*., (1993) studied the seasonal variations in the spathes produced. It indicated that the reproductive phase was much active from April to September during which period 65-70 per cent of spadices were opened. The traditional tall (ECT) had two peaks, one during March and the other during August. Among the dwarf types, Malayan Yellow dwarf (MYD) and Malayan Green dwarf (MGD) had single peak during August while Ayiramkachi (AY) had two peaks during August and June. However, the rate of spathe production is likely to differ in different agroclimatic regions depending upon various environmental factors.

2.2.5 Button shedding

Shedding of button or female flower in an inflorescence is a common phenomenon in coconut and has great economic bearing on the yield of coconut. Gadd (1923) reported that water deficiency affected not only the setting of nuts in coconut plantation but also resulted in severe shedding of nuts especially after prolonged period of drought and particularly after the onset of rain. Patel (1938) reported that shedding of button is high during August, September and November and slightly less during the other months. There does not appear any relationship between the shedding and rainfall and the drought. It is generally greater in dwarf than in tall palms, and varies from year to year within a variety. Gangolly *et al.,* (1956) showed that nearly 70% of potential nuts were lost within the first month after fertilization. In contrast, Abeywardena and Mathes (1971), working in Sri Lanka showed that only about 24% of potential nuts were lost within the first two months after fertilization, but that 40% was lost during the third and fourth month and further 2% during the fifth and six months after fertilization, leaving only about 33% of initial nuts at the time of harvest.

Shedding is found to be high in southwest monsoon season and low in cold weather (Marar and Pandalai, 1957). During heavy rainfall, pollination is hampered which eventually depressed the yield during November-December of ensuing year (Davis and Gosh, 1982). Rao (1988) highlighted that if intensity of rainfall is high, the button shedding is also high. It is probably due to lack of pollen and pollinating agents during the heavy rains as well due to waterlogging in coconut gardens leading to physiological drought, resulting in hypodermal thickening up to the root cap reducing the area of absorption of nutrient from the soil. The study also indicated a significant correlation between button shedding and minimum temperature. Rao and Nair (1988) reported that 83% of nuts from inflorescence that opened during the southwest monsoon (June-September) were shed but only 39% of those that opened during the winter (December-February). Shedding of button or female flower in an inflorescence is a common phenomenon in coconut and has great economic bearing on the yield of coconut. The physiological reasons for shedding of button nuts and for immature nut fall are discussed by Sudhakara (1991). Sudden alteration in soil temperature and soil moisture leads to heavy button shedding and immature nut fall in coconut (Karunanithi *et al.*, 2002). Bai *et al. (2003)* reported that button shedding have two peaks in all the varieties, one during summer month and other during monsoon. The study also indicated that shedding of buttons is directly related to the number of female flower production.

2.2.6 Coconut Yield

The highest yield at Kasragod is generally obtained in May, during the summer, and the lowest in October during the northeast monsoon (Vasudevan and Satyabalan, 1959). Abeywardena and Fernando, 1963 reported that in Sri Lanka the highest yield is generally obtained in May and June, during the southwest monsoon and the lowest in November and December. Distinct yield variations have been recorded in coconut tracts with high temperature, rainfall, and relative humidity. Bhaskaran and Leela (1976) reported that low and erratic rainfall had great influence on yield. They also reported that soil moisture plays a major role in the development and production of spadix which reflect on the final yield. However, heavy and continuous rain and wind had antagonistic effect on pollination and fertilization. This results in poor yield in the corresponding harvest. Marar and Pandalai (1959) reported that hot weather rains followed by dry spell reduced the yield due to immature nut fall. Henry Louis and Annappan (1980) studied the environmental effects on coconut yield and reported that high temperature, rainfall, relative humidity and high wind had significant but negative correlation with the yield of nuts. They recorded significant difference in yield during the four seasons of the year resulting in the major and minor harvest. The annul yield of the palm is subject to considerable fluctuations principally through weather aberrations. Marar and Pandalai (1957) reported that hot weather season accounts for more than a third of the total period. The nuts harvested in hot weather season show all round superiority except in the percentage of oil when compared to the nuts harvested in the other seasons of the year. Oil content is somewhat more in the nuts harvested in northeast monsoon and cold weather seasons.

2.3 IMPACT OF DROUGHTS ON COCONUT PRODUCTION

Park (1934) observed that the severe drought experienced in 1931 in Puttalam district of Sri Lanka affected nut yield for about two years, with the maximum effect occurring about 13 months after the end of the drought. This was confirmed by Rao (1986) who showed that the effect of drought on nut yield was high between the eighth and twelfth month after the drought. Information on the effect of drought on nut yield is scanty. Rao (1985) attempted to classify the effect of drought by calculating ‘aridity’ indices - based on rainfall, pan evaporation and the water balance parameters. He reported that drought effects of adult palm are characterised by bending of leaves, wilting in lower whorls, reduction in female flowers, shedding of buttons, immature nut fall and drastic decline in nut production. Rethinam (1987) also reported the drought management in coconut gardens. Rao (1988) used the “index of moisture adequacy (I_{ma}), based on ratio between actual and potential evapotranspiration for assessing the drought affects. He showed that nut yield exceeded 45 nuts/palm/year when the Ima in the previous year was greater than 30% while the nut yield was less than 30 nuts/palm/year when it is 15%.

Mahindapala (1984) suggested that, in general, yields would be unsatisfactory if a dry spell exceeds 90 days for tall varieties or 75 days for dwarf varieties. Kumar *et al*., 2007 studied variations in nut yield of coconut and dry spell in different agro-climatic zones of India in detail. He reported that in view of the long duration (44 months) between the inflorescence initiations to nut maturation, the occurrence of dry spell in any one year would affect the yield for the subsequent three to four years. It can be inferred that the longer dry spell affects the nut yield for next four years to follow with stronger impact on fourth year, irrespective of the total rainfall.

2.4 COCONUT YIELD FORECASTING MODELS

The influence of weather parameters on crop production varies differently during various stages of crop growth and development. The extent of weather influence on crop yield depend not only on the magnitude of weather variables but also on the distribution pattern of weather during the crop season. The crop development from sowing/transplanting to harvest responds to environmental fluctuations that are predominantly weather-induced. The important weather variables, which drive crop growth and its development are rainfall, solar radiation, vapour pressure deficit, maximum and minimum temperatures. It is understood that the effect of the driving forces (weather elements) on crop development finally decides the total dry matter production under homogeneous environment. To quantify the crop weather relationship, the necessary tools should be through crop - weather modelling. The forecast of crop production before harvest are relevant for various policy decisions relating to storage, distribution, pricing, marketing and import-export policies. The incidence and severity of insect pests and diseases are one of the major causes of reduction in crop yield which is also dependent indirectly on weather variables. Therefore several weather relationships are used in forecasting crop yield. Only thing is that the crop weather model cannot be applied in all agroclimatic zones for operational purpose. They are more location specific. Hence, reliable and timely forecast for a given crop in a particular location provide important and useful input for proper, foresighted and informed planning, mores so, in agriculture with full of uncertainties. Agriculture is now- a- days has become highly input and cost intensive. Under the projected climate change scenario, forecasting of various aspects relating to agriculture has become much more relevant as a part of climate change adaptation. Baier (1977) classified the crop weather models into three basic types and they are as follows:

1. Empirical statistical models
2. Crop weather analysis models
3. Crop growth simulation models.

The most commonly used model in crop forecasting is empirical statistical models. In this approach one or several variables (representing weather or climate, soil characteristic or time trend) are related to crop responses such as yield. Weighting coefficient in these equations are by necessity obtained in an empirical manner using standard statistical procedure such as multi regression analysis. Several empirical statistical models were developed all over the world. The independent variables included weather variables agrometeorological indices, and soil and crop characteristics or combination of all the above. This statistical approach does not easily lead to an explanation of the cause and effect relationships, but it is very practical approach for the assessment or prediction of crop yields.

In contrast to the empirical regression models, the Joint Agricultural Weather Information Centre employs the crop weather analysis models that simulate accumulated crop responses to selected agrometerorological variables as a function of crop phenology. Observed weather data and derived agrometeorological variables are used as input data. Such model does not require a formulated hypothesis of the basic plant and environmental process; thus, the input data requirements are less stringent but the output information is more dependent on the input data. Therefore, crop weather analysis models are practical research tools for the analysis of crop responses to weather and climate variations when only climatological data are available.

A crop - growth simulation model may be defined as a simplified representation of the physical, chemical, physiological mechanisms underlying the plant and crop growth processes. These models simulate the day-to-day assimilation of photosynthetic material based primarily on the exchange of energy and mass among the various growth processes taking place in a plant. Such models are very complex and require the knowledge of both biological and meteorological environment. They are useful for studying the physiology of crop growth and development. Unlike empirical statistical model, a simulation model demands large quantum of information with respect to interaction of soil-plant-atmosphere continuum and predicts numerous parameters of crop production. Crop simulation models are not the total alternative to field experimentation, but it reduces the cumbersome field experiments considerably.

Once the crop simulation model is validated or standardized for a particular crop/variety under a given environment, a lot of information on crop growth and productivity as influenced by weather parameters, fertilizers, irrigation and soil parameters can be generated within hours. The simulation models can generate information on different crop management and cultural practices *viz.* age of seedlings, optimum plant population, spacing, time of fertilizer application and its dose, number of irrigations required during the crop season and yield expected in a given weather situation. A trial on time of planting of a variety or selection of a variety suitable for a location require at least three years of field experimentation. In contrast, a validated model can give precise information on the above aspects in no time. Thus scientists can reduce lot of agronomic trials and save their time and energy if the simulation models are tested and validated. Simulation provides the insight into crop weather relationships, explain why some factors are more important for yield than others, suggests factors likely to have statistical significance and provides the basis for new experiments on processes which are apparently important but not yet sufficiently understood. Thus the simulation approach does not replace the statistical approach, but complementary to it.

Weather variables play an important role in determining the coconut palm growth, development and yield. The influence of weather on coconut yield in fact starts from inflorescence initiation and lasts till nut maturity (Rajagopal *et. al.,* 1996). The time lag between inflorescence initiation to nut maturity is almost 44 months. The coincidence of critical sensitive biotic events of coconut with unfavourable weather results in drastic decline in nut yield. Prediction of coconut yield is of vital importance for policy makers and it is a challenge to researchers since it has a prolonged reproductive phase. In a perennial crop like coconut, the yield response to weather variables is cumulative and not sporadic as the spadix formation is a continuous process within the coconut palm. Hence, studying the effect of a particular weather variable without giving adequate cumulative weightage will not be proper and scientific since the coconut palm has prolonged reproductive phase. It takes one - and - a- half years for the tip of a leaf to emerge in the crown. After a leaf becomes visible, it requires at least six months for the production of flowers. The production of the fruit may require another nine months (Menon and Pandalai, 1960). Thus, under the natural conditions, it will take two years and nine months before an input response is visible in the production of mature nuts.

The coconut is a perennial crop and it has a prolonged reproductive phase of 44 months from the initiation of inflorescence primordium to full maturity of the nuts. The influence of weather on the coconut yield is a cumulative function of seasonal conditions prevailing in the period of 44 months after primordial initiation (Bhaskaran and Leela, 1977). In an unique paper, Patel and Anandan (1936) explained that the annual nut yield is influenced by January to April rains for two years previous to harvest, together with the rains in January to April of the year of harvest. However, thirty to fifty percent yield decline in coconut was seen in the subsequent year due to severe soil moisture stress that occurred during summer 1983, 1985 and 1989 (Rao *et al*., 1993). As the drought intensity during the summer with reference to coconut was in increasing trend, the coconut yield was adversely affected very much during the recent decades (Rao, 1988). The predictive models based on climatic variables are more meaningful than those developed without them by various authors such as Reynolds (1979) and Silva de Sumith (1985) using biometric characters. Efforts were also made to forecast the coconut yield using biometrical characters by Peris (1989**)** and Jacob Mathew *et al*., (1991). Prabhakaran *et. al.,* (1991) had estimated the coconut yield using the partial harvest data and juvenile characters. Another attempt was done to predict coconut yield by Jose *et al*., (1991) using foliar nutrient levels.

Abeywardena (1968) developed a crop forecasting model based on monthly rainfall parameters using the data from 1935 to 1966. The estimated nut yields were close to observed values. However, the validity of the model for anticipating yields has not been tested. He also reported that any rains in excess of 35-36 cms in any month during September - December were harmful to the crop in Sri Lanka because the temperature is low and humidity is high during the period. Abeywardena (1983) later developed an empirical statistical model to forecast yields in Sri Lanka based on eight variables. These eight variables defined as `drought indices` for eight different agro ecological regions are derived from the monthly rainfall data taking into consideration the minimum requirement of soil moisture for optimum production. The errors in the estimated values for some years were very large. But no alternative methods had been developed and use of drought indices was more meaningful and useful than use of actual rainfall. George (1988) had developed prediction models for estimating yield of coconut by evolving different empirical, statistical and crop weather models based on the data and their comparative efficiencies were tested by means of four criteria and models I and III were found to give the best fit. Saraswathi and Mathew (1988) used 15 years data on total monthly rainfall as 12 independent variables to predit yields in each of the ten districts of Kerala. Though the coefficients of determination of these models were reasonably high, there were two degree of freedom for error and few of the parameters were significant at the 5% level. Pillai *et al.*, (1988) also attempted to forecast yield using linear regression model, $Y= f (X_1, X_2)$, where X_1 is the total rainfall for the five month period from the sixteenth to twentieth month and X_2 that from the fourth to the month prior to harvest, but the coefficient of this model was not sufficient to obtain useful predictions.

A predictive model (R^2 = 0.91) with climatic variables (maximum relative humidity, sunshine duration, vapor pressure and minimum air temperature at different periods) was developed by Vijaya Kumar *et al.*, (1988). Peiris (1991) had developed a model (R^2 = 0.89) to predict yield a year ahead based on six variables derived from monthly rainfall distribution one year earlier. The validity of the model was tested for seven different yield groups. The model was flexible to use, but the percentage of error for the seven groups varied from 1.9 to 40%. From this model, yield for a given year could be predicted by the middle of May in the year before the harvest, but its use is limited by the paucity of such climate data. Abeywardena (1993) predicted coconut yield of Sri Lanka an year head based on drought index (R^2 = 0.96). Based on the experimental data on coconut yield at RARS, Pilicode, an attempt was made to estimate coconut yield seven months ahead using agroclimtic indices (Rao and Subhash, 1996). The equation developed (R^2 = 0.94) were in good agreement with the actual and estimated values. Peiris and Thattil (1998) had developed parsimonious models using maximum temperature, after noon humidity and evaporation. These three variables explain how the spathe development during the growth period responded to climate variables without physiological parameters. A common model was also developed (R^2 = 0.81) $p<0.002$) to estimate the annual yield 18 months in advance using maximum temperature, after noon relative humidity and evaporation. He also reported that these three variables influence the microclimate around the crown of the palm for utilizing solar radiation in dry matter portioning and thereby nut production. Rao *et al*., (1999) had developed (R^2 = 0.97) a multiple linear regression equations for forecasting coconut production of Kerala state seven months ahead based on agro climatic indices.

Coconut yield at Andaman and Nicobar islands was estimated using the Artificial Neural Network by Balakrishnan *et al*., (2005). Kumar *et al*., (2008) simulated coconut growth, development and yield with the InfoCrop - coconut model. The study simulated trends in phenological development, total dry mass and its partitioning, and nut yield agreed closely with observed values, although a 15% error was observed in few cases. Considering that field measurements have an experimental error of 10 -15% and wide variation existed within treatments, the model adequately simulated the effects of management practices and agro-climatic conditions over short periods. Agro-climatic wise validation of the InfoCrop coconut simulation model was carried out in this study for the first time in India. The relationships between weather parameters and coconut yield at CARI, Portblair with lag periods were studied with multiplayer perception neural network were studied by Balakrishnan *et al*., 2005. The results revealed that neural network has the capability to forecast the coconut yield. Peiris, *et al*., (2008) used seasonal climate information to predict coconut production in Sri Lanka based on quarterly rainfall. The regression model integrates both climate and technology effects developed to predict annual coconut production of Sri Lanka with high fidelity (R^2 = 0.94).

Palaniswami *et al*., (2008) had developed a fuzzy neural network for coconut yield prediction. The fuzzy membership values of the independent variables (daily mean air temperature, relative humidity, sunshine hours and soil moisture in the root zone) were used as the layer for the network. The correlation coefficient between predicted and observed yield was 0.98 with Root mean square error of 11.77%. They also reported that the proposed method captured the non - linear relationships between the climate, soil and yields of coconut production system. Kumar *et al*., (2009) developed weather descriptive models for prediction of coconut yield in different agro - climatic zones of India. The prediction models with 3 - and 4 - year lag had high R^2 values. The models differed for usage of parameters in different agro-climatic zones, indicating the relative importance of these parameters in respective conditions for realizing the nut yield in coconut. This study also indicated that relative humidity and temperature play important role during the ontogeny of inflorescence and nut development. They also reported that the descriptive models based on weather data can be used for prediction of coconut yield two to four years in advance with in acceptable range of accuracy.

Satheesh Babu *et al*., (1993) studied the effect of monthly rainfall on coconut productivity over Kerala. The result indicated that March and May rainfall during the current year, one year, two year, three year lag period had significant positive correlation with productivity whereas rains during January and November had negative influence. The results also indicated that rest of the months have no significant influence on coconut productivity. Excess rainfall during March to May was not found harmful probably due to the accelerated transpiration facilitated by a high temperature and low humidity (Shanmugham, 1973).

2.4 CLIMATE CHANGE

2.4.1 Introduction

Climate Change has emerged as the one of the most serious environmental concerns of our times. Climate change and climate variability in recent decades are subjects of world wide discussion as the weather related disasters viz., droughts, floods, ice storms, dust storms, hail storms, land slides, heat and cold waves and thunder clouds are not uncommon over one or another region of the world. The year 1998 was one of the recent weather related disasters, which caused hurricane havoc in Central America and floods in China, India and Bengladesh. Canada and New England in US suffered heavily due to ice storm in January. Vat fires in Siberia burned over three million acres of forests. In 2005 also, weather related disasters across the world were noticed. Human and crop losses are the worst phenomena in such weather disasters, affecting global economy to a considerable extent.

The most imminent climatic changes in recent times is the increase in the atmospheric temperature due to increased levels of greenhouse gases such as carbon dioxide (CO_2), methane (CH_4), ozone (O_3), nitrous oxide (N_2O) and chlorofluoro carbons (CFCs). Because of the increasing concentrations of those radiative or greenhouse gases, there is much concern about future changes in our climate and direct or indirect effects on agriculture (Garg *et al.,* 2001; IPCC, 2001; Krupa; 2003; Aggarwal, 2003; Bhatia *et al.*, 2004). The carbon dioxide (CO_2) concentration was in the steady state at 280 ppm till the pre industrial period (1850). It was rising since then at the rate of 1.5 to 1.8 ppm per year. The concentration of CO_2 is likely to be doubled by the end of 21st century (Keeling *et al.,* 1995). According to IPCC (2007) “Climate variability refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all temporal and spatial scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability). Climate change refers to a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer). Climate change may be due to natural internal processes or external forcing, or to persistent anthropogenic changes in the composition of the atmosphere or in land use".

2.4.2 The Global scenario

The Intergovernmental Panel on Climate Change (IPCC, 2007) reported that mean global surface air temperature increased by 0.74°C (0.56 to 0.92) °C in past 100 years. The linear warming trend over the 50 years from 1956 to 2005 was 0.13 [0.10 to 0.16]°C per decade. The temperature increase is widespread over the globe and is greater at higher northern latitudes. Global GHG emissions due to human activities have grown since pre-industrial times, with an increase of 70% between 1970 and 2004. The atmospheric concentrations of CO_2 and CH_4 in 2005 exceed by far the natural range over the last 650,000 years. Global increases in CO_2 concentrations are due primarily to fossil fuel use, with land-use change providing another significant but smaller contribution. It is very likely that the observed increase in CH_4 concentration is predominantly due to agriculture and fossil fuel use. The increase in N_2O concentration is primarily due to agriculture.

The Global average sea level rise at an average rate of 1.8 [1.3 to 2.3] mm per year over 1961 to 2003 and at an average rate of about 3.1 (2.4 to 3.8) mm per year from 1993 to 2003. Arctic sea ice extent has shrunk by 2.7 (2.1 to 3.3) % per decade, with larger decreases in summer of 7.4 (5.0 to 9.8) % per decade. The year 2010 is likely to be the warmest year after 1998 as per the latest indications. Severe floods in Pakistan, China and cloud burst in India (Leh in Ladakh region of Jammu and Kashmir) during August 2010 can be due to the effect of global warming. In contrast, severe heat waves and forest fires that occurred in Russia may result in significant reduction in wheat production. Land regions have warmed faster than the oceans. Some extreme weather events have changed in frequency and/ or intensity over the last 50 years. Cold days, cold nights and frosts have become less frequent over most land areas, while hot days and hot nights have become more frequent. Heat waves have become more frequent over most land areas. The frequency of heavy precipitation events (or proportion of total rainfall from heavy falls) has increased over most areas. Impact of climate change on agriculture will be one of the major deciding factors influencing the future food security of mankind on the earth. Agriculture is not only sensitive to climate change but at the same time is one of the major drivers of climate change. The climate sensitivity of agriculture is uncertain, as there is regional variation of rainfall, temperature, crops and cropping system, soils and management practices. The crop losses may increase if the projected climate change scenario leads to frequent occurrence of weather related disasters like floods, droughts, cold and heat waves. Crops respond differently as the global warming will have a complex impact. It is predicted that there will be a 17 per cent increase in the world area of desert land due to the climate change expected, with a doubling of atmospheric CO_2.

2.4.3 The Indian scenario

Climate change is a global problem with unique characteristic and involves complex interactions between climatic, environmental, economic, political, institutional, social and technological processes, which affect locally. India is one of the 27 countries identified as most vulnerable to the impact of global warming. Lal *et. al*., (1995) presents a climate change scenario for the Indian subcontinent, taking projected emissions of greenhouse gases and sulphate aerosols into account. It predicts an increase in annual mean maximum and minimum surface air temperatures of 0.7°C and 1.0°C over land in the 2040s with respect to the 1980s. Since the warming over land is projected to be lower in magnitude than that over the adjoining ocean, the land-sea thermal contrast that drives the monsoon mechanism could possibly decline. However, there continues to be considerable uncertainty about the impacts of aerosols on the monsoon. The UKMO GCM model (Bhaskaran *et al*., 1995) predicts a total precipitation increase of approximately 20% and increase in winter or *rabi* crop season temperature by 1- 4°C with increased CO_2 concentration. The model also predicts a greater number of heavy rainfall days during the summer monsoon or *kharif* period, and an increased interannual variability. Lonergan (1998) estimates that India's climate could become warmer under conditions of increased atmospheric carbon dioxide. The average temperature change is predicted to be in the range of 2.33°C to 4.78°C with a doubling in CO_2 concentrations. Lal *et al*., (2001), Kumar and Ashrit (2001), Kumar (2002) and Kumar *et al*., (2003) also predicted the temperature and rainfall trends over India under varied CO_2 levels.

2.4.4 Temperature and rainfall trends

Climatic variability and occurrence of extreme events are major concerns for the Indian subcontinents. There is need to quantify the growth and yield responses of important crops and also identify suitable land use options to sustain agricultural productivity under this large range of climatic variations. In India, the analysis of seasonal and annual surface air temperatures (Pant and Kumar, 1997) has shown a significant warming trend of 0.57°C per hundred years. The warming is found to be mainly contributed by the post-monsoon and winter seasons. Hingane *et al.,* (1985) studied the mean annual temperature over India during the period 1901-1982. The result indicates about 0.4°C warming during the eight decades (1901-1982). This warming is mainly caused by the post-monsoon and winter seasons and is found to be renounced for the West Coast, the interior peninsula and the north-central and northeast regions of the country.

Kumar *et al.,* (2002) reported that all - India mean surface air temperatures during 1901-2000 were in warming trends during all the four seasons with higher rate of temperature increase during winter and post monsoon seasons compared to that of the annual. Trends in minimum and maximum temperature for the entire country and also for the six homogeneous regions of the country showed a decreasing minimum temperature trend during summer whereas an increasing trend during the winter season and increasing trend in both the seasons for maximum temperature was noticed. Long term variations of surface air temperature at major industrial cities (Culcutta, Bombay, Madras, Bangalore, Pune and Delhi) of India studied by Kumar and Hingane (1988). Gadgil and Dhorde (2005) reported that there is a significant decrease in mean annual and mean maximum temperature over Pune. At the national level, increase of 0.4° C has been observed in surface air temperatures over the past century. A warming trend has been observed along the West Coast, in central India, the interior peninsula, and north-eastern India (NATCOM Report, 2004). However, cooling trends have been observed in north-west India and parts of south India. Kothawala and Kumar (2005) observed that the all-India mean annual temperature has shown significant warming trend of 0.05°C/10 year during the period 1901-2003. The recent period 1971-2003 has shown relatively accelerated warming of 0.22 °C/10 year, which is largely due to unprecedented warming during the last decade. Dash and Hunt (2007) showed marked trends of increasing temperature over the past quarter century, but significant variations in these trends during different seasons and over different regions of India. Marked differences between the variations in minimum temperature in North and South India have been brought out.

Attempts have been made to study the trends in annual and seasonal rainfall over India since the beginning of the last century. Long term trends of Indian monsoon rainfall for the country as well as for smaller subdivision are studied by Paramanik and Jagannathan (1954); Parthasarathy and Dhar (1978); Parthasarathy (1984); Mooley and Parthasarathy (1983), Parthasarathy *et al.*, (1993). Particularly on the All India time scale showed trendless and random nature for a long period of time (Mooley and Parthasarathy, 1984). Rao and Jagannathan (1963), Thapliyal and Kulshreatha (1991) and Srivastsava *et al*., (1992) were also reported that All India southwest monsoon/annual rainfall observed no significant trend. Long term trend in small spatial scale was reported by Koteswaram and Alvi (1969), Jagannathan and Parthasarathy (1973), Jagannathan and Bhalme (1973, Naidu *et al.,* (1999), Singh and Sontakke, N.A. (1999). Its events and periodicities were studied by Venkatesan *et al*., (1997); Rajeevan (2001); Pai and Rajeevan (2006); Goswami and Gauda, (2007); Raju *et al.,* (2007); Ratnam *et al;* (2007). Kumar *et al*., (1992) have found significant increasing trend in monsoon rainfall along the West coast, north Andhra Pradesh and northwest India while significant decreasing trends over Madhya Pradesh and adjoining area, northeast India and parts of Gujarat and Kerala.

Soman *et al.*, (1988) also reported that Kerala rainfall showed significant decreasing trend. Ananthakrishnan and Soman (1988 and 1989) studied the monsoon events in detail utilising the data up to 1980. Joseph *et al.,* (2004) reported that the period of Intra Seasonal Oscillation of South Kerala rainfall during summer monsoon has large inter - annual variability in the range of 23 to 64 days. Rainfall variability during southwest monsoon season over Kerala was studied in detail by Krishnakumar *et al*., (2007). They have reported that the rainfall in June and July was declining while increasing in August and September over the state of Kerala. It was more evident since last 40 years, indicating that there was a shift in monthly rainfall during southwest monsoon season.

Krishnakumar *et al*., (2008) also studied the temperature and rainfall trends at four selected locations in the State of Kerala. The general characteristics of the Indian monsoon were studied Rajeevan *et al*., (2006). A study carried out by Indian Institute of Science (Ravindranath *et al*., 2006) assessed the impact of projected climate change on forest ecosystems in India. The main conclusion is that by 2085, between 68% and 77% of the forested grids in India are likely to experience shift in forest types depending upon projected climate change scenarios. The inconsistencies in the occurrence of monsoon were reported by Ramesh and Goswami, (2007); Francis and Gadgil (2006) using 37 years of rainfall data examined intense rainfall events over the West Coast of India. Guhathakurta and Rajeevan (2007) observed decreasing trend in almost all subdivisions except for subdivisions Himachal Pradesh, Jharkhand and Nagaland, Manipur, Mizoram and Tripura during winter. Annual rainfall showed significant decreasing trend over Chattisgrah, Jhakhand and Kerala. During southwest monsoon, Jharkhand, Chattisgrah and Kerala showed significant decreasing trend in rainfall.

Rao, *et al*., (2008 and 2010) studied the effect of climate change on cropping systems over Kerala. Krishnakumar *et al*., 2009 studied the temporal variation in monthly, seasonal and annual rainfall over Kerala during the period from 1871 to 2005. The analysis revealed that significant decrease in southwest monsoon rainfall while increase in post-monsoon season over the State of Kerala. Rainfall during winter and summer seasons showed insignificant increasing trend. In view of the importance of variability's in rainfall, as indicated above, it would be of interest to study the long - term variation of monthly, annual and seasonal rainfall over Kerala.

2.5 DROUGHT ASSESSMENT

India is an agricultural economy based country. Despite, the share of agriculture sector to GDP of the country is only about 24%, 70% of Indians are dependent on farm incomes, and about 60% of farm cultivation depends on rains. In India, delayed and deficient monsoon seasons severely affect the farmers. The crops and cropping area vary with the rainfall pattern during monsoon and ultimately affect the agricultural production. In past few years, there has been increase in extreme weather events such as drought, flood, heat and cold waves and strong wind etc. India suffered of drought in 2002 with seasonal (June-September) deficit of all India rainfall (19% below normal) after all India drought occurred during June-September, 1987. However, one part or the other parts in the country suffers from drought invariably every year. In 2009, around half of the districts have been declared drought affected. A large number of studies are available on various aspects of floods and droughts. Gregory (1989) has reported that droughts in hyper humid regions of India such as Assam are very in frequent, with the last documented drought in the region dating back to 1900.

Drought prone areas fall in three broad regions of the country (CWC, 1982). Parthasarathy *et al.*, 1987 identified a range of 1- 12 severe drought years for the various meteorological sub-divisions of the sub continent during 1871-1984. Using long time series (1875-1987) of subdivision rainfall data over India, Chowdhury *et al.,* (1989) examined various statistical features of all India drought incidences. A study by Chowdhury *et al.*, (1989) have ranked the year 1918 as the worst drought year of the last century - a year when about 68.7% of the total area of the country was affected by drought. During 2002, twelve out of 36 subdivisions of the country came under the grip of moderate to severe drought when abut 29% of the total area of the country was affected by drought. The seasonal rainfall during the summer monsoon in the country as a whole was 19 percent below normal qualifying 2002 as the first all-India drought since

1987. Rainfall deficits during July were most noteworthy, at a historical low of 51 per cent below normal in 2002.

Of all the major natural disasters, droughts account for nearly 22% of significant damages though the number of deaths is only 3% world wide (De and Joshi, 1998). A comprehensive analysis of Monsoonal droughts by Sikka (1999) has brought out several interesting facts. First the occurrence of drought on All India scale shows an epochal nature. During the last 125 years phenomenal droughts on the All India scale were only four. These years were 1877, 1899, 1918 and 1972 when the seasonal rainfall deficiencies were more than 26% below the seasonal mean rainfall. Sinha Ray and Shewale (2001) studied the probability of drought on sub-divisional scale. The frequency of droughts was generally high over western and central India and northern peninsula. The difference in yield during these drought years as compared to the succeeding year a non-drought year viz : 1982 - 83 and 1987 - 88 were about 218.18 lakhs of tones and about 266.81 lakhs of tones respectively (De *et al*., 2005). Using subdivision wise rainfall and area data, Sen and Sinha Ray (1997) observed a decreasing trend in the area affected by drought in India, which are located over northwest India, parts of central Peninsula and southern parts of Indian Peninsula. Gore and Sinha Ray (2002) made a detailed study of the variability of drought incidence over districts of Maharashtra. Gore *et al*., (2010) using PN examined the probability of drought incidence in the subdivision scale using rainfall data of 319 districts for the period of 1901-2000. The study also examined spatial variation of drought probability over India. The District-wise drought climatology over India for the southwest monsoon season has been examined for the first time using two simple drought indices viz., Percent of Normal (PN) and Standardized Precipitation Index (SPI) over a period of 1901-2003 (Pai *et al*., 2010). Identification of drought incidences over the country as a whole using both PN and SPI yielded nearly similar results.

Chapter III

Data and methodology

3.1 EXPERIMENTAL DETAILS

The experimental site (Plate 3.1) is located in Seed Production-Cum-Demonstration Farm, Coconut Development Board, Vellanikkara (10^0 31'N and 74^0 13'E). Ten (eight year old coconut palms) palms each of the four cultivars were randomly selected for the study (Fig 3.1). Thus altogether 40 palms formed the material for recording phenological observations. The palms selected were grown under uniform management conditions. The cultural and management practices were followed as per the Package of Practices Recommendations of the Kerala Agricultural University (KAU, 2007). The filed experiment was taken up under AICRP on Agrometeorology.

3.1.1 Cultivars

The four test cultivars viz., Tiptur Tall, Kuttiadi (WCT), Kasargod (WCT) and Komadan (WCT) were selected for taking up the field experiment.

3.1.2 Soil characteristics

Soil of the location was clay loam in texture. The physico-chemical properties of experimental sites are as detailed below:

Gravel (%)	-	54.45	pH	-	5.4
Sand (%)	-	39.84	EC (dS/m)	-	0.033
Silt (%)	-	27.49	Org.C (%)	-	1.12
Clay (%)	-	32.67	Available P (ppm)	-	1.86

3.1.3 Climate

The experimental location falls under the humid climate (B_4/ B_3 - type) as per Thornthwaite (1948) climatic classification. The weekly meteorological data for the

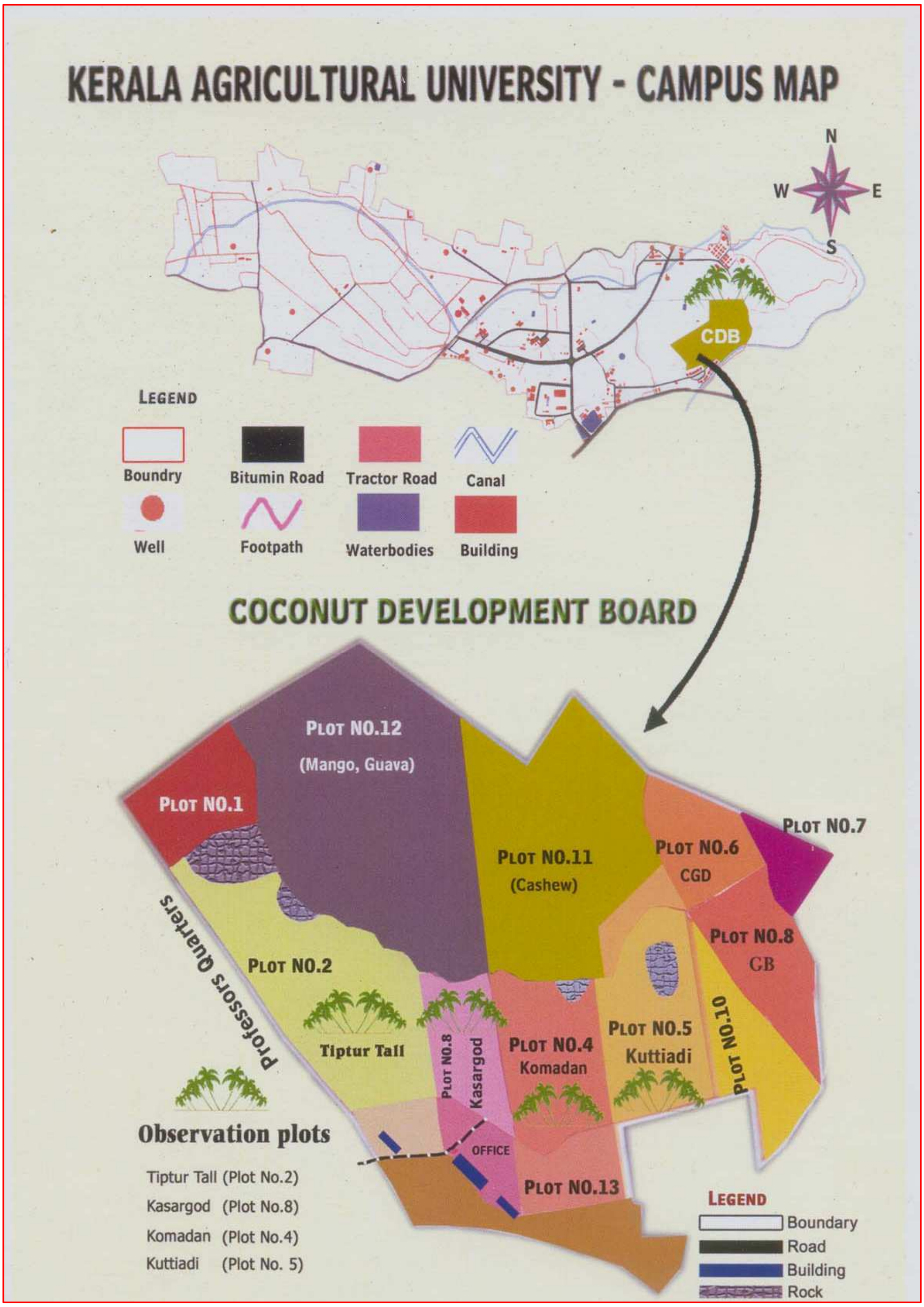


Plate 3.1: Location of experimental plot

TIPTUR TALL

1-2	
3-4	
5-9	78-87
10-12	88-98
13-15	99-116
16-21	117-133
23-31	134…***138:137***...150
32-38	151…***154:160***...168
39-47	169..***171:176:177***..18
48-53	185…***188:198***...201
54-60	202…***205***...220
69-77	221-235

KASARGOD

1-15
16-36
37-49
50…***55***...56
57…***61*****...**68
69…***71:73:75:76***…77
78…***79***...85
86**...*****87:89:92***…94
104-112
113-121

KOMADAN

1-16
17…***21***…35
36…***41***…53
54…***59***...72
73-93
94-114
115…***117:121:124***...13
135...***140:141:146***…151
152…***162***…168
169-185

KUTTIADI

1…***16:17***…26
27…***38:41:42***…53
54…***59:60:61***…68
69…***71:72***...82
83-90
91-97
98-105
106-127
128-143

Figures in red indicate observational palms

Fig. 3.1: Layout of experimental palms

study were collected from the records maintained at the Academy of Climate Change Education and Research, Kerala Agricultural University, Vellanikkara.

3.1.4 Phenological observations

The biotic events viz., leaf, spathe and floral characters were recorded once in a week from February 2002 to June 2007.

3.1.4.1 Leaf characters

1) Number of functional leaves produced monthly
2) Number of leaf shedding monthly

3.1.4.2 Spathe characters

1) Number of spathes presented on the crown at the time of observation
2) Date of spathe emergence.
3) Date of spadix emergence
4) Duration of spathe emergence to spadix emergence

3.1.4.3 Floral characters

1) Number of female flowers produced
2) Number of buttons set
3) Button shedding
4) Monthly nut yield

3.1.5 Meteorological data

Daily meteorological data on maximum and minimum temperatures, relative humidity (morning and evening), rainfall and rainy days, bright sunshine hours and evaporation were collected. The mean values of air temperature, relative humidity and vapour pressure were worked out weekly and monthly and thus the derived weather variables are as follows:

Growing Degree Days (Day °C),

Helio-Thermal unit and Vapour pressure deficit (hPa)

3.1.6 Soil moisture data

Weekly soil moisture observation at different depths (15cm, 30cm, 45cm and 60cm) were carried out at the experiment site during the study period. The moisture percentage is calculated by the simple gravimetric method. Weekly Soil moisture data at different depths viz., 15cm, 30cm, 45cm and 60cm were collected from soil moisture observatory at Vellanikkara and from the experimental plot of coconut for comparison between open and coconut.

3.2 METHODS

The phenological data collected from ten palms of each cultivar were pooled Standard-Meteorological-Week wise to get the mean phenological data of a particular week of a test cultivar. The observations on number of spathes produced, duration of spathe, monthly leaf production and seasonal button shedding, spathe emergence and spathe opening were processed.

3.2.1 Spathe emergence

The number of spathes that emerged monthly was worked out for correlation analysis with weather parameters 29 months prior to the spathe emergence since the primordia for spathe would have developed 32 months before the spadix emergence (Patel, 1938).

3.2.2 Spathe duration

The spathes that emerged in the same standard week were pooled to get the mean duration of spathes of each cultivar. Weather parameters were also averaged in the same way and correlations were worked out using Pearson's Bi-variate correlation technique.

3.2.3 Female flower production

The number of female flowers collected from the observational palms of each cultivar was pooled and the monthly female flower production was worked out. The correlations were worked out between mean monthly female flower production and weather parameters at four critical stages viz., primordia initiation (32 months prior to spadix emergence), branches of inflorescence (16 months prior to spadix emergence), male and female flower stage (11-12 months prior to spadix emergence) and ovary development (6-7 months prior to spadix emergence) as suggested by Rajagopal *et al.*, (1996).

3.2.4 Button shedding

The mean button shedding was worked out corresponding to spathes, which opened during the same standard week and it was correlated with weather parameters.

$$BS = 1- \left[\frac{NFF_1}{NFF_2} \right] * 100$$

Where,

BS- Button shedding (%)

NFF_1- Number of female flowers retained at the end of third month

NFF_2- Number of female flowers at the time of spathe opening

3.2.5 Monthly nut yield

The monthly nut yield collected from the observational palms of each cultivar was pooled to find out the monthly mean production. The number of rainless weeks occurring at each stage of nut development was worked out to study the effect of dry spell on the initiation and development of inflorescence and yield in coconut. The data on female flower production, nut set and nut yield were material employed for the study. To study the association between the weather variables and nut yield of coconut, correlations were worked out in seven critical stages viz., primordia initiation, branch development stage of inflorescence, male and female flower development stage, ovary development stage, spadix emergence stage, button nut size and mature nut stage as these biotic phases are vital for final yield of coconut. The above phases coincide with 44 months, 29 months, 24-25 months, 19-20 months, 12 months, 9 months and 6-8 months, respectively prior to the harvest.

3.2.5 Seasonal average

The whole year was divided into four seasons as suggested by the India Meteorological Department. Four seasons have been identified as follows:

Season	Period
Summer	March-May (3 months)
Southwest monsoon	June- September (4 months)
Post monsoon	October-November (2 months)
Winter	December-February (3 months)

As the phenological observation may vary with the length of seasons, the seasonal monthly means were worked out to maintain uniformity for correlation studies.

3.2.6 Growing Degree Days (GDD)

Growing Degree Days (Day °C) for various phenological events were worked out. A thermal day / Growing Degree Days (GDD) / heat unit is the departure from the mean daily temperature above the minimum threshold temperature (°C). Thermal days for the each phenological event were worked out from the following:

$$GDD = \sum_{i=1}^{n} \frac{(Tmax+Tmin)}{2} - T\ base$$

GDD= Growing Degree Day (Day °C)

T max = Maximum temperature of the day (°C)

T min =Minimum temperature of the day (°C)

$\sum_{i=1}^{n}$ = Summation for day ‘1’ to day ‘n’ when the event occurred.

The base temperature (T-base) is assumed as 13° C for adult coconuts (Rao, 2008).

3.2.7 Helio-Thermal Unit (HTU)

The product of Growing degree day and the number of actual bright sunshine hours of any day is called Helio- Thermal Unit (HTU).

HTU= GDD * Number of actual bright sunshine hours

3.2.8 Vapour Pressure Deficit (VPD)

The difference between the saturation vapour pressure (SVP) and its actual vapour pressure (AVP) is termed as saturation vapour pressure deficit (VPD).

VPD=SVP-AVP

Where,

AVP= Actual Vapour Pressure (Saturation vapour pressure at dew point temperature)

SVP=AVP/RH x 100

RH = Relative humidity

The observations on SVP were computed using the AVP values which were obtained from the hygrometric table.

3.2.9 Statistical Analysis

3.2.9.1 Analysis of Variance

To study the influence of season on different biotic observation of coconut the experimental data were analysed using the Repeated-Measures of ANOVA technique. Repeated-Measures of ANOVA technique is also used to analyse the Seasonal influence on the variety. The significance is tested by F test and the treatments were compared by Duncan’s Multiple Range Test (Snedecor and Cochran, 1983).

3.2.9.2 Estimation of Correlation

The simple correlation (bivariate) was worked out using SPSS package.

3.2.9.3 Principal Component Analysis

To facilitate the prediction of indices, reduction in number of variables is imperative. Hence, Principal Component Analysis (PCA) was used to identify major weather variables which can be used to predict the duration of spathe, button shedding and nut yield. Further, adoption of PCA Analysis has been established scientifically to reduce multi- collinearity among independent variables and to arrive at the best subset of variables for predication models.

3.3 CLIMATOLOGICAL DATA

3.3.1 Rainfall

The data source for monthly rainfall (mm) over Kerala from 1871 to 1994 is the Indian Institute of Tropical Meteorology (IITM) publication entitled “Monthly and seasonal rainfall series for all-India homogeneous regions and meteorological subdivisions: 1871-1994” (Parthasarathy *et al*., 1995). Monthly, seasonal and annual rainfall series of Kerala State were constructed using monthly rainfall data of fixed network of 10 raingauge stations. On an average, there is one raingauge station for every 3886.4 sq. km area**.** The monthly rainfall data for the period from 1995 to 2009 were collected from IITM website (www.tropmet.res.in) for this study.

From the Basic monthly rainfall data, monthly mean, seasonal rainfall, Standard Deviation (SD) and Coefficient of Variation (C.V) and 75 per cent rainfall probability have been computed for each month and for the four seasons viz., pre monsoon, southwest monsoon, post monsoon and winter. The month of March, April and May were considered as the summer season while June to September constituted the southwest monsoon season. October and November was considered post monsoon season while December to February were considered as the winter months. While computing the means for winter rainfall, December of the previous year is included. The percent contribution of monthly and seasonal rainfall to annual rainfall was also calculated for each year as well as for the entire data set to know whether there is any change or shift of rainfall pattern.

A linear trend line was added to the series for simplifying the trends. To support trends in annual and seasonal rainfall, decade - wise shifts in rainfall over

Kerala were also analysed for the period from 1871 to 2009. Temporal changes in seasonal and annual rainfall were also analysed by Mann-Kendall Rank Statistics (t) to conform the significance of the observed trend (Libiseller, C. and Grimall, A. 2002). The values of t were used as the basis of a significant test by comparing it with

$T_t = 0 \pm \ t_g \sqrt{(4N+10)/9N(N-1)}$

Where, tg is the desired probability point of the Gaussian normal distribution. In the present study t_g at 0.01 and 0.05 points have been taken for comparison.

The probability of rainfall at 75 per cent level as suggested by Hargreaves (1977) was used for this study. Rainfall received at 75 per cent level, as dependable rainfall, is the minimum amount of rainfall expected to be received in three out of four years and hence risk involved is relatively less in crop planning. Doorenbos and Pruit (1975), Frere and Popov (1979) and Sakamoto *et al.*, (1984) described a simple ranking method for the computation of dependable rainfall. The method is as follows:

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

Fa(m)= 100 m / n+1

Where n = number of records

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

3.3.1.1 Low pass filter

To understand the nature of trend, the time series of rainfall (percentage departure from long period average) was subjected to a `low-pass filter` in order to suppress the high frequency oscillations, as suggested in WMO Technical Note No 79, (1966) and used by Tyson *et al*., (1975). The weights used were nine ordinates of Gaussian probability curve (ie 0.01, 0.05, 0.12, 0.20, 0.24, 0.20, 0.12, 0.05 and 0.01). The response curve of the Gaussian low pass filter has a response function that is equal to unity at infinite wave length and it tails off asymptotically to zero with decreasing wave lengths (WMO, 1966). It was observed from the filtered series that the trend is not linear but oscillatory consisting of periods of 10 years length or more.

3.3.2 Temperature

Monthly maximum and minimum temperatures recorded by the India Meteorological Department were collected from the National Data centre, IMD, Pune. In addition to the temperature data from the IMD, temperature data from Kerala Agricultural University Research Stations viz., Pattambi, Pilicode, Vellanikkara, Ambalavayal and Pampadumapra were also collected.

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

The Mann-Kendall nonparametric test was applied to the monthly and seasonal temperature data, in order to detect trends.

3.3.2.1 21-point binomial filter

To understand the nature of trend, the time series of temperature anomaly (departure from long period average of 1956-2009) was subjected to a `21- point binomial filter` in order to suppress the high frequency oscillations. Binomial filters are simple and efficient structures based on the binomial coefficients for implementing Gaussian filtering. The filter is a weighted moving average of the data.

Its weights are centred on the year of interest. For the binomial filter, the weights were set to be proportional to the binomial coefficients, in contrast to equal weightings in a simple moving average filter. The weights b_0 to b_N of an N + 1 point binomial filter were computed as follows:

$$b_k = \frac{c_k}{\sum_{k=1}^{N} c_k} \qquad k = 0,1,\ldots\ldots\ldots N$$

$$\text{Where, } c_k = \frac{N!}{k!(N-k)!}$$

3.4 DROUGHT AND CLIMATE SHIFTS

3.4.1 Potential evapotranspiration (PE)

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

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

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

where e = monthly unadjusted PET in cm/month

t = Mean monthly temperature in °C

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

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

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

$$a = 6.75*10^{-7} I^3 - 7.71*10^{-5} I^2 + 1.7921*10^{-2} I + 0.49239$$

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

3.4.2 Water balance

Yearly water balance for the State as a whole was computed for a period of 109 years (1901-2009) using the Thornthwaite and Mather (1955) book - keeping water balance procedure, given by Subrahmanyam (1982). The monthly Aridity Index (I_a), Moisture Index (I_m) and humidity Index (I_h) were computed from 1871 to 2009 using the formulae given below:

$I_a = WD/PE * 100 \qquad I_h = WS/PE * 100 \qquad I_m = I_h - I_a \qquad I_{ma} = AE/PE*100$

Where, AE-Actual Evapotranspiration (mm), PE-Potential Evapotranspiration (mm), WS-Water Surplus (mm), WD-Water deficit(mm).

Intensity of droughts was worked out as per the procedure given by Subrahmanyam and Subramaniam (1964). They were classified on the basis of the percentage departure of aridity index from the median as Moderate, Large, Severe and Disastrous.

Departure of Ia from median	**Drought intensity**
$<1/2\sigma$	Moderate
$1/2\sigma$ to σ	Large
σ to 2σ	Severe
$>2\sigma$	Disastrous

The yearly, decadal and tri-decadal trend in aridity index was computed using liner trend method. Similar exercise was done in the case of moisture index for knowing any climatic shift in the State during the study period. The summer drought and its impact on coconut production were worked out using the mean aridity index from November to May month.

Thornthwaite`s climate scheme (1948) was followed to study climate shifts

The scheme is as follows:

Climate classification	**Climate type**	**Moisture index(Im)**
C_2	Moist sub humid	0-20
B_1	humid	20-40
B_2	humid	40-60
B_3	humid	60-80
B_4	humid	80-100
A	Perhumid	Above 100

3.5 DROUGHT AND COCONUT PRODUCTION

The monthly coconut production at RARS, Pilicode, CPCRI, Kasaragod, Aralam farm, Kannur, CDB, Farm, Vellanikkara, RARS, Kumarakom and CRS, Balaramapuram were collected along with monthly rainfall and temperature for analyzing the effect of drought on monthly nut yield. The details of location and data period are as follows:

Name of the station	**Data period**
CPCRI, Kasaragod	1995-2001
RARS, Pilicode	1979-2001
Aralam farm, Kannur	1995-2001
CDB, Farm, Vellanikkara	2002-2007
RARS, Kumarakom	1980-2001
CRS, Balaramapuram	1980-2001

In addition to this, monthly auction price of coconut were also collected from 1979 to 2010 at RARS, Pilicode for analyzing the effect of climate variability on coconut price. Year wise coconut area, production and productivity for the State of Kerala published by the Coconut Development Board, Govt of India were collected to study the effect of drought, climate variability/change on coconut production and productivity.

3.6 NON-ORTHOGONAL ANOVA

Non orthogonal analysis of variance was carried out for the data to assess the effect of weather on yield with frequency as weight. To calculate the frequency, weather variables and coconut production/productivity were grouped into different class intervals of same length. Weather variables belonging to the production /productivity range were counted. Monthly average of temperature, rainfall and index of moisture adequacy along with annual coconut production and productivity were used for analysis. Non-orthogonal analysis was carried out using the SPSS 17.

3.7 YIELD PREDICTION MODELS

The humidity index from June to September and index of moisture adequacy from October to May were considered along with coconut area one year prior to harvest for predicting coconut production and its productivity seven months ahead. The monthly agroclimatic indices (I_{ma}, I_h) were considered for 42 months before the harvest as the primordium initiation to coconut harvest takes about three and half years for predicting coconut production of Kerala as a whole. A multiple linear regression was developed using the above agroclimatic indices for predicting coconut production and its productivity seven months ahead. The data from 1961-62 to 2006-07 were used for developing regression equation.

The vector autoregression (VAR) model is one of the most successful, flexible, and easy to use models for the analysis of multivariate time series. It is a natural extension of the univariate autoregressive model to dynamic multivariate time series. It often provides superior forecasts to those from univariate time series models and elaborate theory-based simultaneous equations models. A Vector Auto Regression (VAR) system can be expressed in the following form:

A VAR model describes the evolution of a set of *k* variables over the same sample period (t = 1, ..., T) as a linear function of only their past evolution. The equation for a ***p-th order VAR***, denoted ***VAR(p)***, is

$$y_t = c + A_1 y_{t-1} + A_2 y_{t-2} + \cdots + A_p y_{t-p} + e_t,$$

where c is a $k \times 1$ vector of constants, A_i is a $k \times k$ matrix (for every $i = 1, ..., p$) and e_t is a $k \times 1$ vector of error terms.

The VAR model consists of a series of Ordinary Least Squares (OLS) regressions in which each dependent variable is a function of the independent variables and lagged values of the dependent and independent variables.

A VAR model describes the evolution of a set of k variables over the same sample period ($t = 1, ..., T$) as a linear function of only their past evolution. The equation for a ***p-th order VAR***, denoted ***VAR(p)***, is

$$y_t = c + A_1 y_{t-1} + A_2 y_{t-2} + \cdots + A_p y_{t-p} + e_t,$$

where c is a $k \times 1$ vector of constants, A_i is a $k \times k$ matrix (for every $i = 1, ..., p$) and e_t is a $k \times 1$ vector of error terms

The analysis was done using Gretl 1.8 Software which is a good package for time series data analysis. VAR is a multivariate model used to capture the evolution and the interdependencies between multiple time series, generalizing the univariate Auto Regressive models. All the variables in a VAR are treated symmetrically by including for each variable an equation explaining its evolution based on its own lags and the lags of all the other variables in the model. The coconut yield forecasting model was developed based on the average index of moisture adequacy (I_{ma}) from December to May of the year prior to harvest and coconut yield.

Chapter IV

Phenology of coconut

4.1 INTRODUCTION

Phenology is the study of the response of living organisms to seasonal and climatic changes in which they live. This term was first introduced in 1853 by the Belgian botanist Charles Morren and is derived from the Greek words *phaino*, meaning “to appear or to come into view” and *logos*, meaning “to study.” Phenology is the science that measures the timing of life cycle events for plants, animals, and microbes, and detects how the environment influences the timing of those events. In the case of flowering plants, these life cycle events are phenophases which include leaf budburst, first flower, last flower, first ripe fruit, leaf shedding and so on (Haggerty and Mazer, 2008). Thus, phenologists record the dates that these events occur, and they study how environmental conditions such as temperature and precipitation affect their timing. Phenology is the study of the timing of recurring bio-logical events, the interaction of biotic and abiotic forces that affect these events, and the interrelation among phases of the same or different species. Seasonal changes include variations in the duration of sunlight, precipitation, temperature, and other life- controlling factors.

The effect of these factors on cashew phenology across the cashew growing tracts of the country was studied in detail by Rao, 2002. Unlike seasonal fruit crops or annual crops, the effect of seasonal factors on the biotic events of perennial crop like coconut cannot be assessed since it has a complex prolonged reproductive phase of more than three - and - a- half years from primordium initiation to harvest of coconut. In annual crops, the effect is manifested immediately or during the course of the year whereas in the case of perennial crops like coconut, the effect on phenology and yield characters is discernible only after some time lag. The effect of a particular season noticed on phenology of coconut may be due to the delayed effect of earlier seasons as coconut palm undergoes various prolonged crop stages before harvest takes place. The evolution and development of inflorescence of the coconut palm has been traced by Patel (1938). The primordium of the inflorescence is reported to develop in the leaf axils about 32 months before the opening of the inflorescence. A schematic representation of different biotic events from primordium initiation to final harvest of coconut is depicted in Fig. 4.1

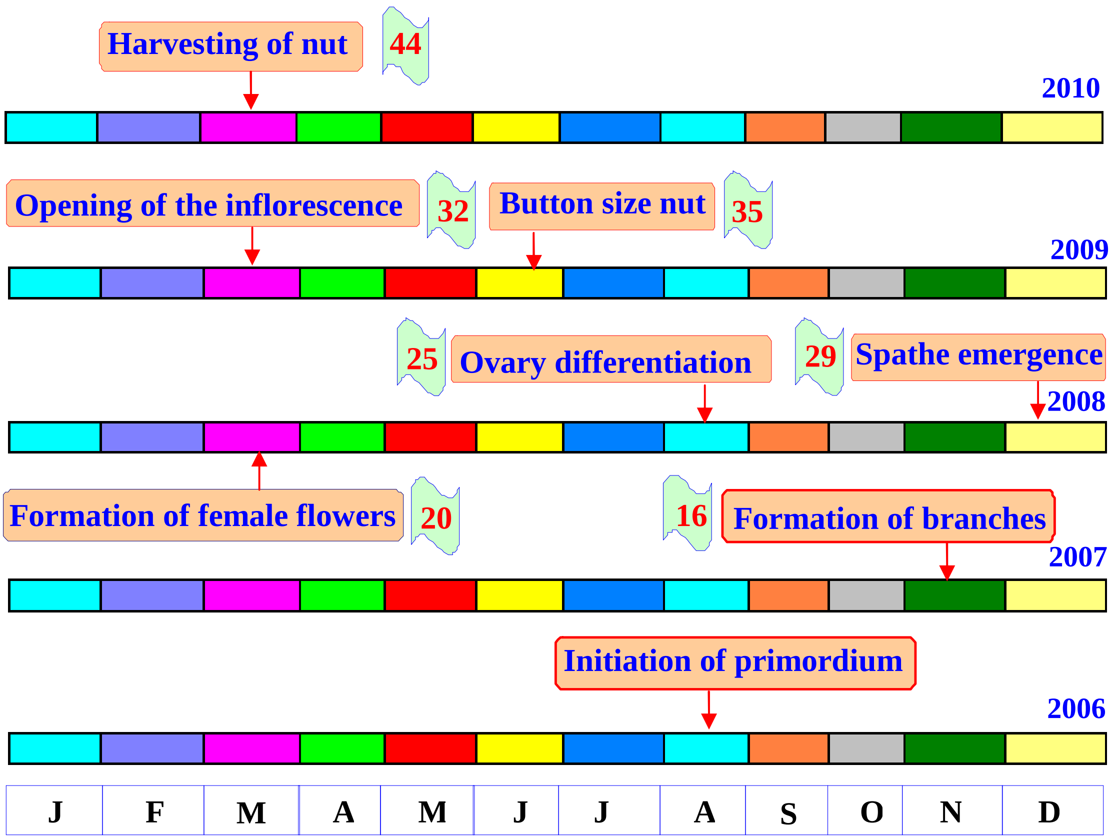


Fig. 4.1: Evolution and development of inflorescence in coconut

The primordia of the branches of florescence develop in about 16 months and male and female flowers in about 11 and 12 months, respectively before the opening of the inflorescence. The ovary is first differentiated about 6-7 months before the opening of the inflorescence. Various environmental factors during the period of 32 months before the inflorescence opens do affect the yield of coconut. The spathe opens (opening of the inflorescence) at the 32nd month and fertilization takes place during the 33rd month after initiation of primordium in coconut. The nut development process takes place through female flower fertilization of buttons, the button development into coconut through active and ripening phases and harvest of nut, what we see in the form of coconut. It takes 10 to 12 months after female flower fertilization depending upon the season. A significant altitudinal effect on nut development is also noticed as it takes 14 to 18 months when it is grown above the altitude of 600 metres in the equatorial region. Considering various factors that are involved, both biotic and abiotic in the process of nut development in coconut, studies in coconut phenology were undertaken systematically with weekly/monthly observations from 2002 to 2007 to understand the response of various biotic events to seasonality and thereby to weather conditions in the Central zone of Kerala. Such an intensive phenological study of coconut is the first of its kind.

4.2 FUNCTIONAL LEAVES

The coconut frond known as leaf is large, long and pinnate. The fleshy mid-rib held by the rachis is fringed with 100 to 120 leaflets on either side at equal distance. In tall cultivars, the whole leaf measures more than 5 m while the petiole 1.3 m. There are about 30-40 leaves in a healthy crown with a similar number of leaf primordia, each differentiated about 30 months before it emerges as a 'sword leaf'. A mature leaf is 3-4 m long and has 200-250 leaflets. In dwarf, it measures much above the petiole. In adult coconut palms, leaves are produced in succession but the interval between the openings of two successive leaves is found to be influenced by the seasonal conditions. On an average, one frond is produced in a month. A leaf remains on the palm for about 3 years and thereafter is shed leaving a permanent scar on the trunk.

4.2.1 Varietal and seasonal effects

The mean annual number of functional leaves present on the crown was high (30.3/palm) in Tiptur Tall while the least (28.0/palm) in Komadan (Table 4.1). It indicated that Tiptur Tall appears to be better among the four cultivars tested in terms of functional leaves present on the crown. On an average, the annual functional leaves present on the crown were more than twenty-nine in number.

Table 4.1: Average number of functional leaves/palm in different seasons from 2002 to 2007

Season	Tiptur Tall	Kuttiadi	Komadan	Kasaragod	**Mean**
Summer (Mar-May)	29.8	27.6	27.1	28.8	**28.3**
SWM (Jun.-Sept)	29.5	27.8	27.3	29.1	**28.4**
PM (Oct.-Nov)	30.9	29.6	28.6	30.3	**29.9**
Winter (Dec.-Feb.)	31.1	29.7	29.0	30.2	**30.0**
Mean	**30.3**	**28.7**	**28.0**	**29.6**	**29.2**

It is clear that the functional leaves present on the coconut crown vary from variety to variety at any given point of time in a given location. The effect of seasonality indicated that the functional leaves on the crown were less (28.3/palm) during summer and rainy season (28.4/palm) and high during winter (30.0/palm) and post monsoon season (29.9/palm). All the four cultivars tested showed a similar seasonal trend with reference to functional leaves retained on the coconut crown. It also revealed that the mean monthly functional leaves on the coconut crown present are more from October to March when compared to that of April to September (Fig. 4.2).

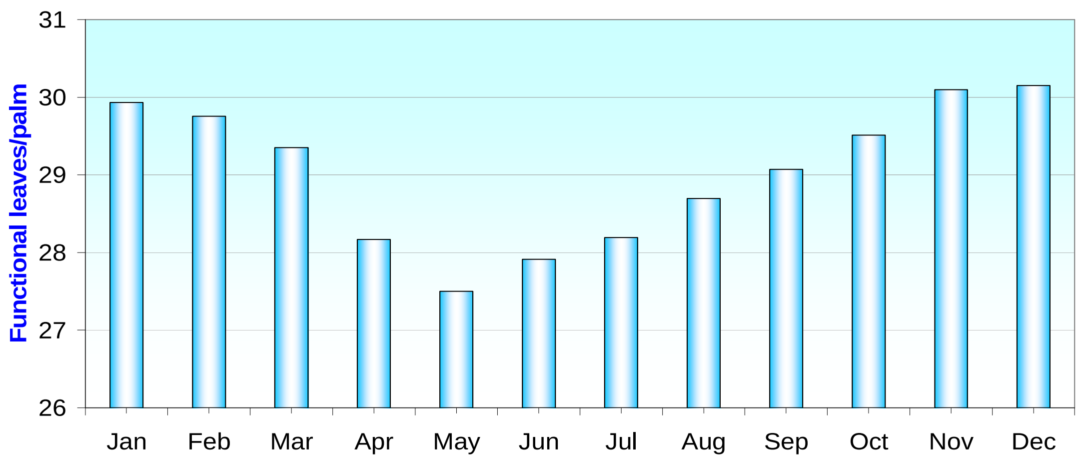


Fig. 4.2: Mean monthly functional leaves

The functional leaves present on the crown was maximum (30.2/palm/month) during December while minimum (27.5/palm/month) was observed May. It clearly indicated that the number of functional leaves gradually increased from June and reaches to its peak in December and thereafter decreasing gradually from January and reaches to its lowest in May.

The reason for more number of leaves during the post monsoon and winter seasons can be attributed to the fact that the food materials that are stored in the palm during the southwest monsoon season would not have fully been utilized during the monsoon season because of unfavourable weather conditions such as high rainfall, high soil moisture, low surface air temperature, less vapour pressure deficit, low wind speed and low sunshine hours. These factors restrict optimum evapotranspiration and thereby results in poor uptake of nutrients during the monsoon. Once the southwest monsoon period is over, palms are exposed to favourable weather/atmospheric conditions for greater photosynthesis. The assimilation of food material and translocation of assimilates into the vegetative part-leaf lead to more leaf development from October to March. Hot weather conditions during summer (maximum temperature of 33-36°C) in the absence of soil moisture may restrict the production of functional leaves and thereby, resulting in low functional leaves that are present on the coconut crown in addition to the leaf shedding during summer.

The monthly and yearly data on number of functional leaves indicated that there was a decline from March 2004 and continued till February 2005 (Table 4.2).

Table 4.2: Functional leaves/palm present on the crown during 2004 and 2005

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Mean**
2004	30.3	30.2	28.9	25.8	23.7	24.7	25.4	25.9	25.8	26.1	27.1	30.3	**27.0**
2005	28.6	29.0	29.2	28.2	28.0	28.9	29.3	30.0	30.4	31.0	30.8	30.5	**29.5**
Mean	**29.9**	**29.8**	**29.3**	**28.2**	**27.5**	**27.9**	**28.2**	**28.7**	**29.1**	**29.5**	**30.1**	**30.2**	**29.0**

It indicated that the effect of severe soil moisture stress in functional leaves is felt for a period of one year. As the functional leaves on the crown remain at least more than three years and another 44 months inside the cabbage, the soil moisture stress may not effect the production of current functional leaves. Therefore, the affect of soil moisture stress on functional leaves could be attributed to leaf shedding only, thereby decrease in functional leaves in 2004, 2005 and 2006 were the good years in terms of functional leaves present on the crown.

The maximum temperature, temperature range (difference between maximum and minimum temperature), vapour pressure deficit, sunshine and evaporation during 30 months prior to leaf emergence had negative correlation while rainfall, soil moisture and number of rainy days had significant (0.01 level) positive correlation with number of functional leaves present in the crown. It revealed that the number of functional leaves was low when the vapor pressure deficit 30 months prior to the leaf emergence was high and vice - versa. In contrast, rainfall and soil moisture influenced the functional leaves favourably 30 months prior to the leaf emergence.

4.2.3 Leaf shedding in coconut

The number of leaves shed at a given time depends upon the age and nature of palm, season, agronomical practices and variety. Under favourable conditions, the coconut leaves of good regular bearers remain on the palm for three to three-and-a-half years, after they have fully opened out. The life of a leaf from the time of the formation of primordium to the time it is shed, will be about five to six years depending upon the conditions of the tree. The shedding of leaves varies from season to season depending upon weather conditions. The seasonal leaf shedding in the test cultivars of coconut are summarized below based on the weekly data collected from 2002 to 2007 at coconut farm, Vellanikkara.

4.2.3.1 Varietal and seasonal effects

The mean number of leaf shedding was maximum (1.2/palm/month) in Kasaragod while minimum (0.9/palm/month) in Tiptur Tall (Table 4.3). On an average, the number of leaf shedding was more than one in a month. However, it revealed that the mean annual number of leaf shedding was more 14.4 (palm/year) in Kasaragod while low (11.6/palm/year) in Tiptur Tall.

Table.4.3: Average number of leaf shedding in different seasons from 2002 to 2007

Season	Tiptur Tall	Kuttiadi	Komadan	Kasaragod	**Mean**
Summer (Mar-May)	1.5	2.0	1.8	1.8	**1.8**
SWM (Jun.-Sept)	0.7	0.6	0.7	0.7	**0.7**
PM (Oct.-Nov)	0.5	0.5	0.6	0.7	**0.6**
Winter (Dec.-Feb.)	1.1	1.5	1.2	1.6	**1.4**
Mean	0.9	1.1	1.0	1.2	**1.1**
Annual	**11.6**	**13.9**	**13.0**	**14.4**	**13.0**

The monthly leaf shedding in coconut was maximum in April (1.9/palm/month), followed by February and March (1.8/palm/month each), January (1.4/palm/month) and December (1.1/palm/month). The leaf shedding was minimum (0.5/palm/month each) in September and October, followed by August and November (0.6/palm/month). The leaf shedding in coconut decreases from June reaching to its minimum (0.5/pal/month) in September and October, thereafter it gradually increases from December onwards, reaching to its maximum (1.9/palm/month) in May (Table 4.4).

Table 4.4: Month - wise leaf shedding of different cultivars in coconut

Month	Cultivar				**Mean**
	Tiptur Tall	Kuttiadi	Komadan	Kasaragod	
January	1.0	1.8	1.3	1.6	**1.4**
February	1.4	1.8	1.8	2.1	**1.8**
March	1.5	2.2	1.8	1.8	**1.8**
April	1.7	2.2	1.9	2.0	**1.9**
May	1.3	1.4	1.4	1.5	**1.4**
June	0.9	0.8	0.8	0.9	**0.8**
July	0.9	0.6	0.8	0.8	**0.8**
August	0.7	0.5	0.6	0.6	**0.6**
September	0.4	0.6	0.6	0.6	**0.5**
October	0.5	0.5	0.4	0.6	**0.5**
November	0.4	0.5	0.6	0.7	**0.6**
December	0.9	1.4	0.8	1.5	**1.1**
Mean	**0.9**	**1.1**	**1.0**	**1.2**	**1.1**

Increase in leaf shed was seen from December and ceased in June with the onset of monsoon. The leaf shed from June to November is minimum (less than one leaf /palm/month) while maximum (1-2 leaves/palm/month) from December to May

As a whole, the seasonal leaf shedding was maximum (41.2%) during summer (Fig 4.3) and winter (31 %) while minimum (12.4 %) during post monsoon and rainy seasons (15.3%). The results obtained were in accordance with Patel (1938) but not in agreement with Sampson (1923).

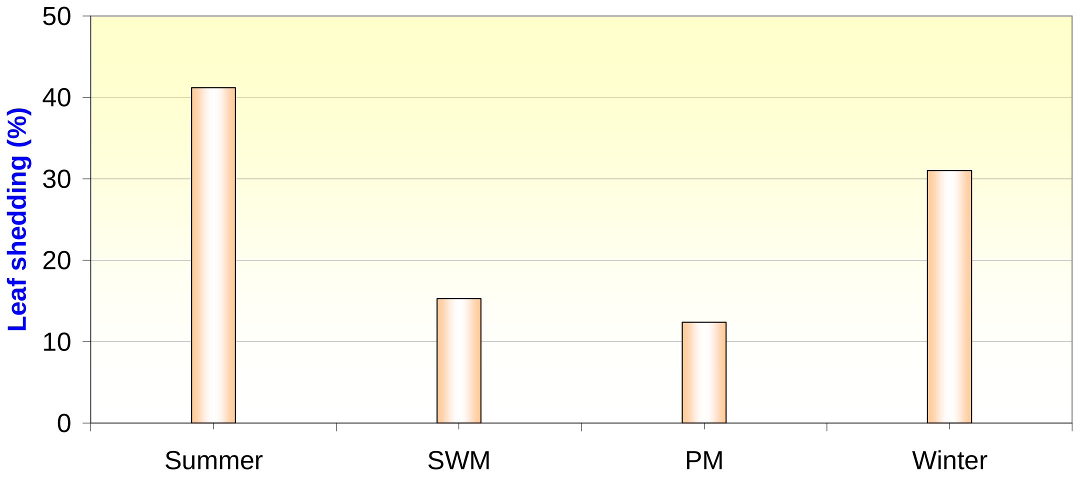


Fig. 4.3: Mean seasonal leaf shedding (%) in coconut from 2002 to 2007

Temperature, both air and soil, vapour pressure deficit, sunshine and evaporation had significant (0.01 level) positive correlation while rainfall and soil moisture had significant (0.01 level) negative correlation with leaf shed.

Rise in ambient air temperature, temperature range, vapour pressure deficit, low rainfall coupled with high evapotranspiration and high solar radiation prevailed during the summer season might have enhanced the drying rate of older leaves on the crown under the rainfed conditions. The palms selected for the study were grown under rainfed conditions. This may be one of the reasons, why, the shedding of leaves was maximum during the summer season. Relatively more leaf shedding in winter in this part of Kerala can be attributed to strong dry winds that blow through the Palghat gap from November/December to January/February. All the cultivars recorded maximum leaf shedding during summer 2004 due to prolong dry spell from 1st November to 28th March 2004 coupled with high air temperature (1-3°C rise against normal). It led to high dry rate of older leaves, resulting in leaf shedding (Fig 4.4). In addition to this, the average soil moisture during winter 2003 and summer 2004 was only 9.2%, which was the lowest when compared to 2002-03 (13.7%), 2004-05 (10.3%) 2005-06 (10.2%) and 2006-07 (10.3%).

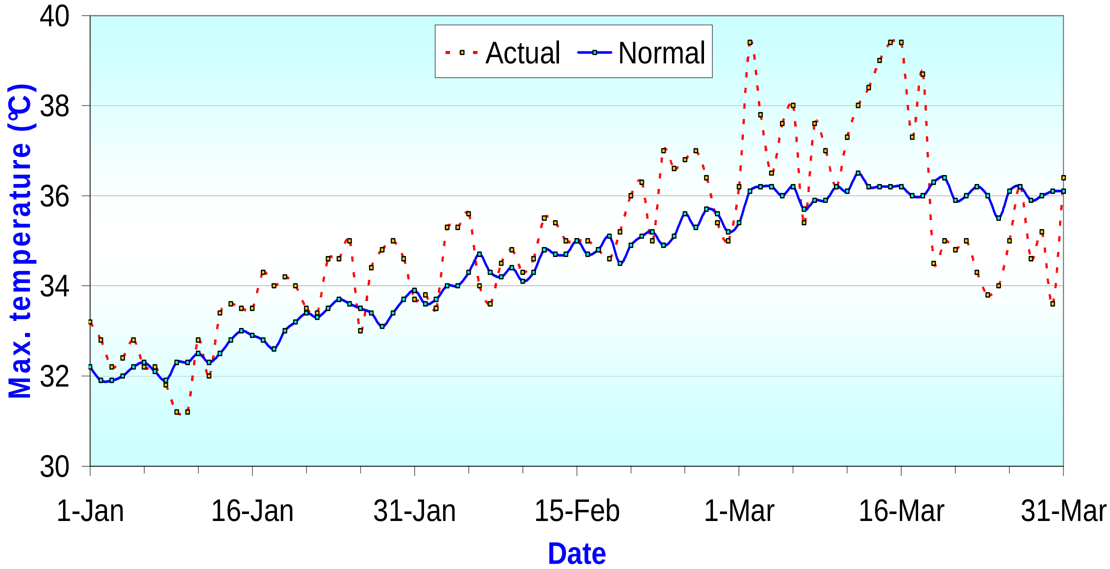


Fig. 4.4: Daily maximum surface air temperature against normal from 1st January to 31st March, 2004

It revealed that leaf shedding is dependent on weather factors in addition to dryness with the age of leaf. The utmost lower leaves are known as physiologically non - functional leaves to a large extent. Rainfall and soil moisture influenced leaf shedding to a large extent. When rainfall is more and soil moisture is enough, the leaf shedding is low. In contrast, the leaf shedding was high when rainfall was negligibly low with less soil moisture. The above relationship is illustrated graphically in Figs 4.5 and 4.6.

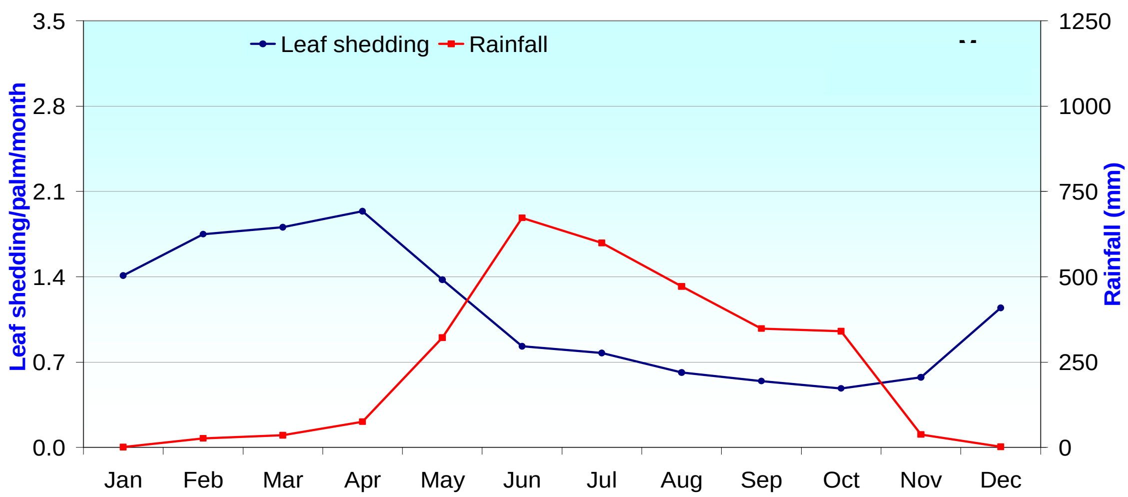


Fig. 4.5: Mean monthly rainfall versus leaf shedding in coconut

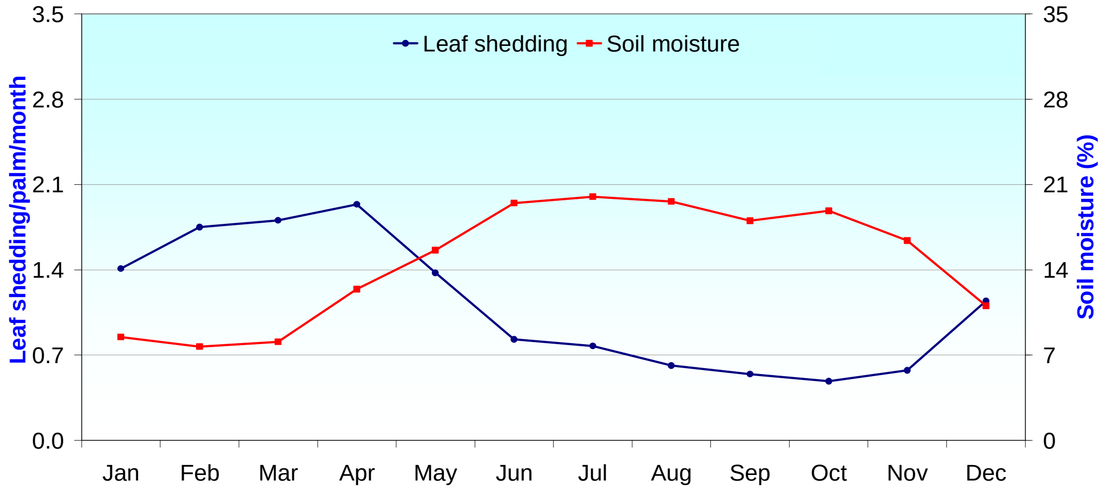


Fig. 4.6: Mean monthly soil moisture versus leaf shedding in coconut

Similarly, the leaf shedding followed the vapour pressure deficit, which is an index of dryness (Fig 4.7). The illustration clearly indicated that rainfall, soil moisture and vapor pressure deficit influenced the leaf shedding to a large extent. The monthly vapour pressure deficit was maximum in February (16.4hPa) while the lowest during July (4.2hPa).

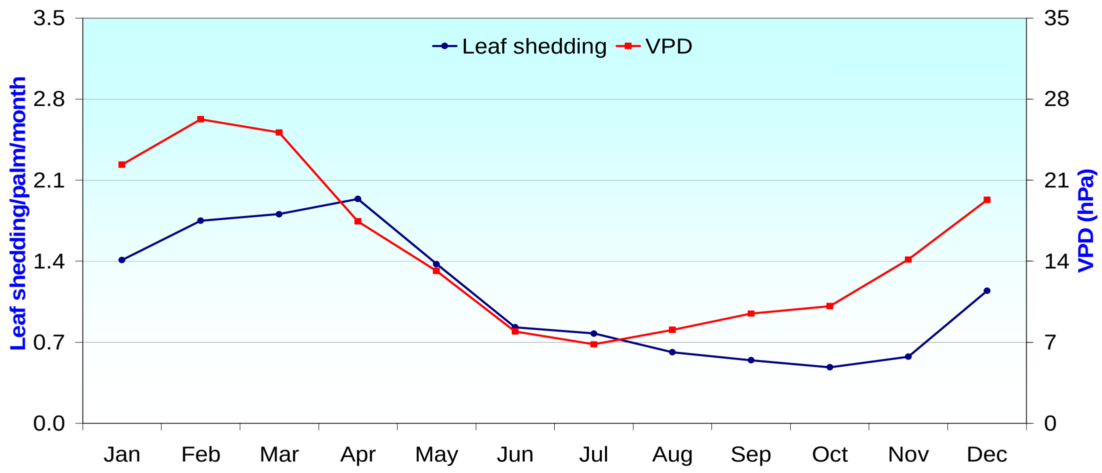


Fig. 4.7: Mean monthly vapor pressure deficit versus leaf shedding in coconut

4.3 SPATHE EMERGENCE IN COCONUT

The coconut inflorescence is enclosed in a double sheath or spathe, the whole structure known as a 'spadix' which is borne singly in the axil of each leaf. A leaf like bract that encloses the spadix is called spathe. Coconut inflorescence known as the

spadix is stout erect, pear shaped, and measuring 0.5 to 1.5 m long and protected by a double sheath of a spathe depending upon the cultivar/variety. Commencement of flowering is an important stage in the life of coconut. The age at which the trees commence flowering varies according to the variety, age of palm, soil and climate. The Coconut palm begins flowering after three to five years under good management conditions and continuously produces flowers. The evolution and development of inflorescence of the palm has been traced by Patel (1938). The primordium of the inflorescence is reported to develop in the leaf axils about 32 months before the opening of the inflorescence. The period reckoned from the initiation of the tall coconut palm with its indeterminate flowering habit, comes to flowering by the seventh year after planting. The first inflorescence emerges from the 45th leaf axil and thereafter one inflorescence arises every month from the subsequent leaf axils (Menon and Pandalai, 1958). At any given time, different stages of reproductive phase starting from spathe emergence to ripening of nuts are noticed on the crown of coconut. Keeping this in view, an attempt has been made to understand the weather effects on spathe emergence in the central zone of Kerala and the results are summarised below:

4.3.1 Varietal and seasonal effects

The monthly spathe emergence showed that it was maximum in November (1.6/palm/month), followed by May (1.3/palm/month), March (1.2/palm/month) and October and December (1.1/palm/month). The spathe emergence is minimum (0.7/palm/month) in September, followed by June, July and August (0.9/palm/month each). All the four cultivars tested also showed similar trend (Table 4.5). The average number of spathes emerged in Tiptur Tall was high (13.0/palm/annum), followed by Kuttiadi (12.5/palm/annum) and Kasaragod (12.4/palm/annum) while the least (12.1/palm/annuam) in Komadan. It indicated that Tiptur Tall appears to be better among the four cultivars tested in terms of spathe emergence. On an average, the annual number of spathes emerged were between 12 and 13 in a coconut palm depending upon the cultivar/variety.

Table 4.5: Monthly spathe emergence/palm in coconut

Month	Cultivar				**Mean**
	Tiptur Tall	Kuttiadi	Komadan	Kasaragod	
January	1.0	1.1	1.0	1.1	**1.0**
February	1.1	0.8	0.9	1.0	**0.9**
March	1.2	1.2	1.1	1.2	**1.2**
April	0.8	1.0	0.9	0.9	**0.9**
May	1.3	1.3	1.3	1.3	**1.3**
June	0.9	0.8	0.9	0.9	**0.9**
July	0.9	0.9	0.9	0.9	**0.9**
August	0.9	0.9	0.9	0.8	**0.9**
September	0.7	0.8	0.7	0.8	**0.7**
October	1.0	1.2	0.9	1.0	**1.1**
November	1.8	1.6	1.6	1.5	**1.6**
December	1.2	1.0	1.1	1.1	**1.1**
Total	**13.0**	**12.5**	**12.1**	**12.4**	**12.5**

The seasonal influence on spathe emergence showed that it was maximum (30.7%) during post monsoon season while minimum (19.1%) during southwest monsoon (Fig. 4.8). The spathe emergence was intermediary in summer (26.3%) and winter (23.9%). In all the cultivars, the trend in spathe emergence was similar as all the four cultivars showed the maximum spathe emergence during the post monsoon while minimum during southwest monsoon.

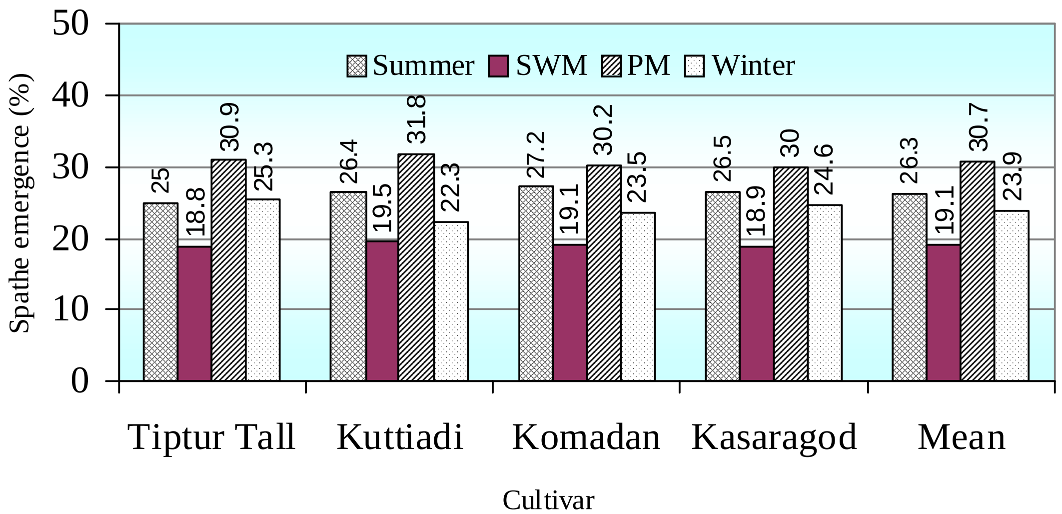


Fig. 4.8: Percentage spathe emergence in coconut during different seasons from 2002 to 2007

Repeated measures ANOVA revealed that there is significant seasonal influence on the variation of spathe emergence ($F (3, 108) = 48.322$ $P < 0.001$). DMRT analysis also indicated that the seasonal spathe emergence is significant. It revealed that the seasonal influence on spathe emergence is significant whereas the varietal and seasonal interaction is not significant on spathe emergence. A significant difference between the mean seasonal variation of spathe emergence in coconut ($F (3, 36) = 40.027$, $P<0.001$) was also noticed.

4.3.2 Effects of Weather

The mean seasonal spathe emergence from year to year during the study period also varied significantly, having maximum (1.19/palm/month) in 2005-06 while minimum (0.97/palm/month) in 2002-03. Low spathe production during 2002-03 and 2004-05 was mainly attributed to summer drought during 2002 and 2004 (Table 4.6). Whenever the summer drought occurs, the spathe emergence in the following season is comparatively low. That is, why, the spathe emergence was low during the southwest monsoon during 2002 (0.50/palm/month) and 2004(0.68/palm/month).

Table 4.6 Mean monthly spathe emergence (palm/month) in coconut

Season	Summer (Mar-May)	SWM (Jun.-Sept)	PM (Oct.-Nov)	Winter (Dec.-Feb.)	**Mean**
2002-03	1.00	0.50	1.40	0.97	**0.97**
2003-04	1.30	1.03	1.30	1.00	**1.16**
2004-05	0.93	0.68	1.20	1.10	**0.98**
2005-06	1.27	1.05	1.35	1.10	**1.19**
2006-07	1.27	0.98	1.40	1.00	**1.16**
Mean	**1.13**	**0.85**	**1.35**	**1.03**	**1.09**

The maximum emergence of spathe during post monsoon season can be attributed to the fact that rainfall, temperature and bright sunshine hours 29 months before (May-June) the spathe emergence coincide with the receipt of optimum pre monsoon and monsoon rainfalls, which results in better availability of soil moisture. The Soil moisture available in 2002, 2003, 2004, 2005 and 2006 was 15.7%, 19.6%, 19.5%, 18.7% and 17.5% respectively. It may favour congenial environment for the primordia initiation and thus maximum spathe emergence during post monsoon season. The unfavourable weather conditions such as low rainfall, number of rainy days and high temperature coupled with more sunshine hours 29 months prior to the spathe emergence (January- April) would have played a major role in low emergence of spathes during the southwest monsoon season. Maximum temperature recorded during this period was more than 34°C in all the years. Vapour pressure deficit was also very high coinciding with this period in all the years. The amount of rainfall received from January to April was only 73 mm in four rainy days during 2000. Moisture availability in the soil was only 5.4%. It is obvious that the low rainfall during summer was the major factor in low spathe emergence during southwest monsoon of 2002, 2004 and 2006 (Fig. 4.9). The low spathe emergence during winter season coincides with 29 months lag period, corresponding to southwest monsoon period. During the above period, high rainfall beyond a critical value might have affected the spathe emergence adversely as it results in waterlogging and lack of aeration in coconut root zone.

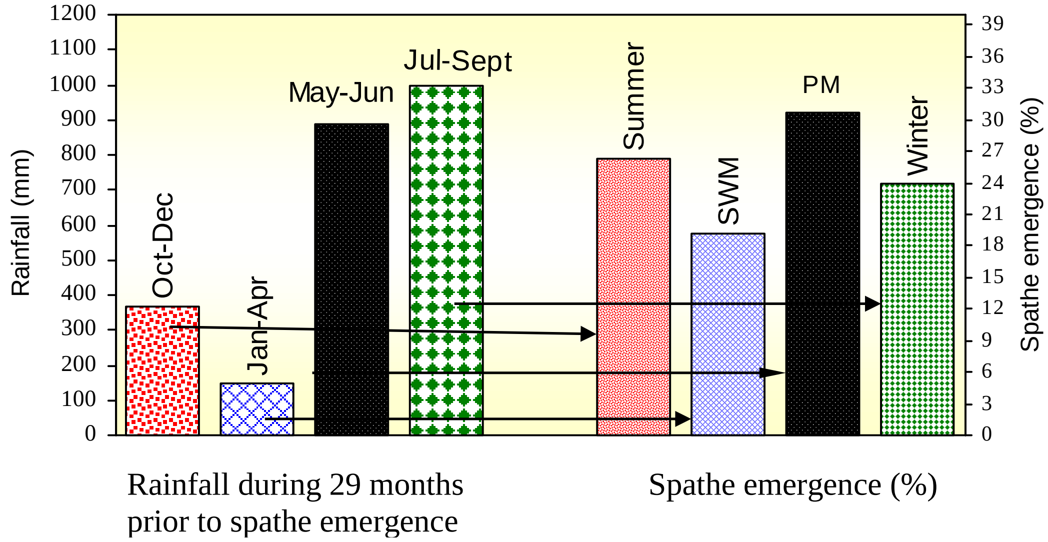


Fig. 4.9: Average rainfall during 29 months prior to the spathe emergence

Rainfall recorded during the above period in 2002, 2003, 2004, 2005 and 2006 was 1049.8 mm, 940 mm, 984.8mm, 1036.4 mm and 965.3mm respectively. The available sunshine hours is comparatively very low during the above period, it is an order of less than 4.0 h/day in all the years. The effect of maximum temperature, vapour pressure deficit and soil moisture during 29 months prior to spathe emergence and seasonal variation in spathe emergence is shown in Fig. 4.10.

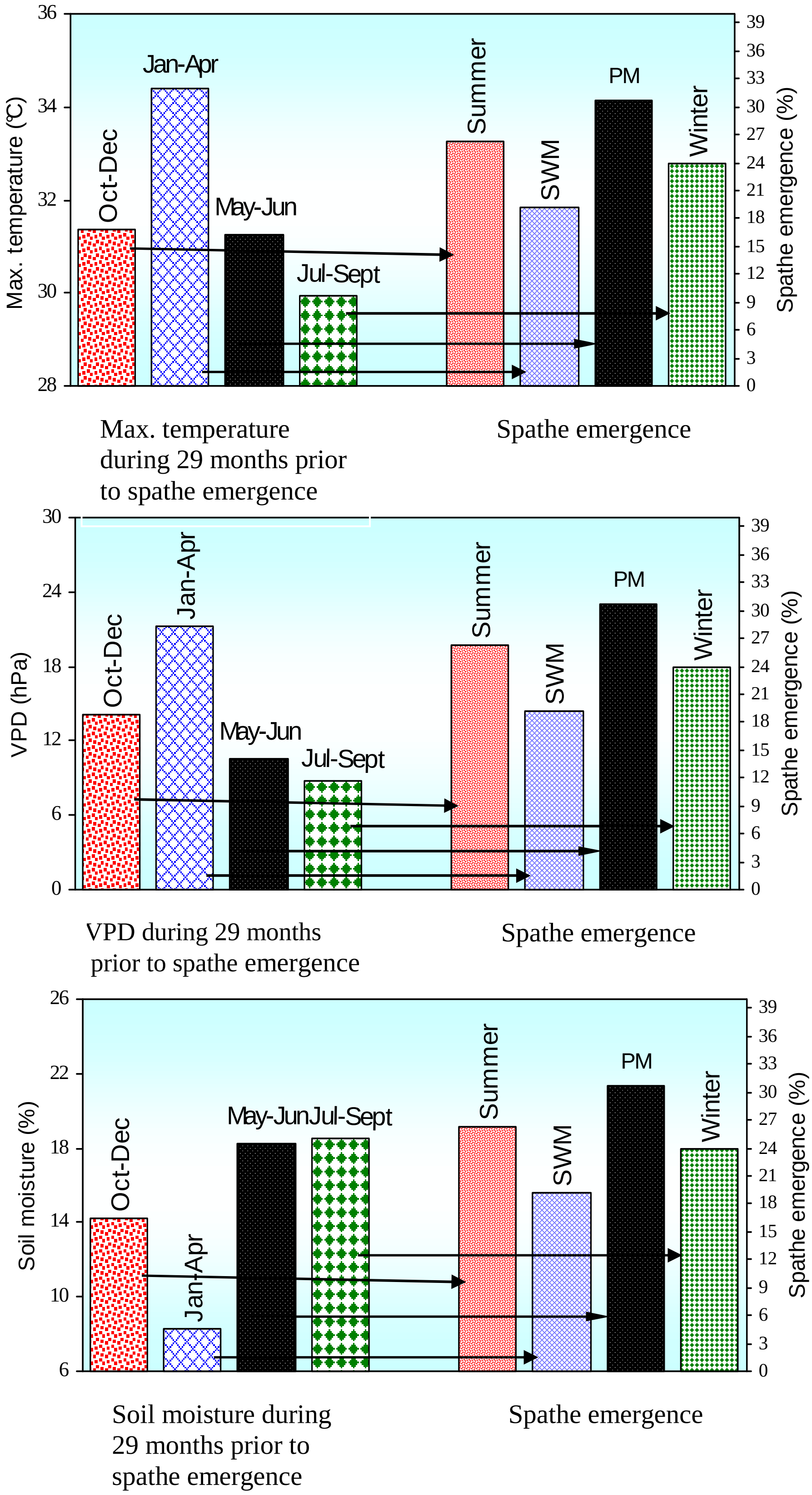


Fig.4.10: Influence of maximum temperature, vapour pressure deficit and soil moisture during 29 months prior to spathe emergence

The correlation between the monthly spathe emergence and weather parameters of 29 months lag period indicated that the temperature both air and soil, vapour pressure deficit, sunshine and evaporation had significant negative correlation at 0.01 level while rainfall and soil moisture had significant (0.01 level) positive correlation with spathe emergence

4.3.4 Varietal and seasonal effects on number of spathes present in coconut

The mean monthly number of spathes present on coconut crown in Tiptur Tall was high (2.8/palm/month), followed by Kuttiadi (2.7/palm/month) and Kasaragod (2.6/palm/month) while the least (2.3/palm/month) in Komadan. It indicated that Tiptur Tall appears to be better among the four cultivars tested in terms of number of spathes present on the crown. On an average, the number of spathes present on the crown was more than 2.6 per palm per month and varied between 2.3 and 2.8/palm/month depending upon the variety. It also indicated that there is no significant variation among the varieties.

The number of spathes present on the coconut crown was maximum (3.4/palm/month) in January while minimum (1.9/palm/month) in September (Table 4.7). The number of coconut spathes gradually increases from October to January and thereafter gradually decreased; reaching to a minimum of 1.9 spathes present on the crown in September. Similar trend was exhibited in all the cultivars. The effect of seasonality indicated that the number of spathes present on coconut crown was less during southwest monsoon (2.1/palm/month) and high (3.3palm/month) during winter when compared to that of summer (2.6/palm/month) and post monsoon season (2.5/palm/month).

Table 4.7: Monthly spathe present on the crown of different cultivars in coconut

Month	Cultivar				**Mean**
	Tiptur Tall	Kuttiadi	Komadan	Kasaragod	
January	3.7	3.4	3.0	3.4	**3.4**
February	3.6	3.1	2.9	3.3	**3.2**
March	3.2	2.8	2.6	3.0	**2.9**
April	2.9	2.6	2.3	2.7	**2.6**
May	2.6	2.4	2.1	2.4	**2.4**
June	2.5	2.4	2.0	2.2	**2.3**
July	2.5	2.4	2.0	2.2	**2.3**
August	2.3	2.2	1.8	2.0	**2.1**
September	1.9	2.0	1.8	1.9	**1.9**
October	2.1	2.4	2.0	2.2	**2.2**
November	2.8	2.9	2.5	2.7	**2.8**
December	3.6	3.4	2.9	3.3	**3.3**
Mean	**2.8**	**2.7**	**2.3**	**2.6**	**2.6**

It also showed that the number of spathes present in all the test varieties was similar as they decline gradually from summer and increased during post monsoon and it reaches to its peak in winter and thereafter decreased (Table 4.8).

Table 4.8: Average number of spathe/palm in different seasons from 2002 to 2007

Season	Tiptur Tall	Kuttiadi	Komadan	Kasaragod	**Mean**
Summer (Mar-May)	2.9	2.6	2.3	2.7	**2.6**
SWM (Jun.-Sept)	2.3	2.2	1.9	2.1	**2.1**
PM (Oct.-Nov)	2.5	2.7	2.3	2.5	**2.5**
Winter (Dec.-Feb.)	3.6	3.3	2.9	3.3	**3.3**
Mean	2.8	2.7	2.3	2.6	**2.6**
Annual	**11.3**	**10.8**	**9.4**	**10.6**	**10.5**

The percentage number of spathes present on the crown was maximum (31.8 %) in winter, followed by summer (25%) while low (19.8 %) in southwest monsoon. It was intermediary (23.4%) during post monsoon season (Fig. 4.11).

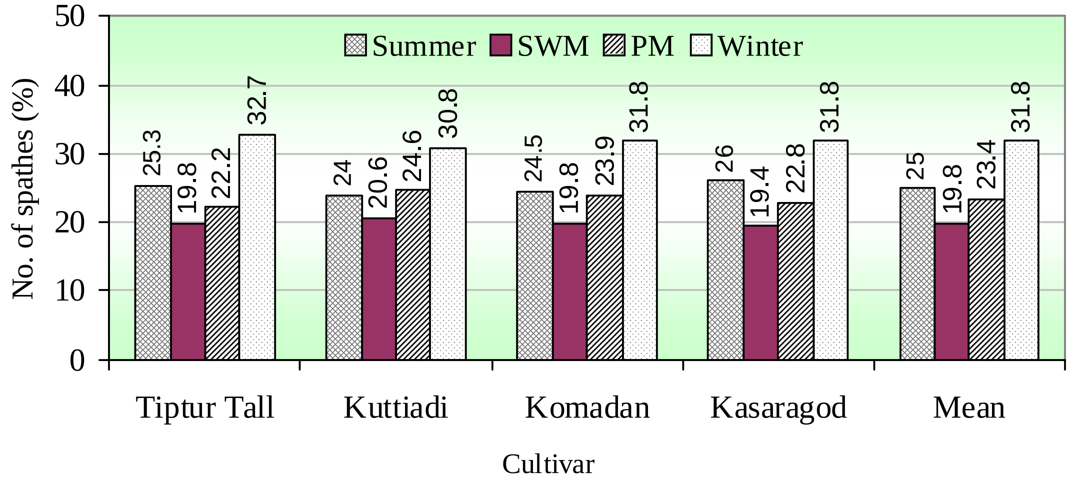


Fig. 4.11: Percentage of spathes present on the crown during different seasons

4.3.4.1 Effects of weather

The number of spathes on the crown from year to year during the study period varied significantly, having maximum (3.4/palm) during winter 2004-05 and minimum (1.4/palm) during southwest monsoon 2002 (Table 4.9). The number of spathes present on the crown was maximum (3.2 - 3.4/palm/month) during winter season in all the years tested. During summer 2002 (2.4/palm) and 2004 (2.3/palm), the spathes present on the crown was low when compared to summer 2003 (2.8/palm), 2005 (2.9/palm) and 2006 (2.9/palm). Similar was the trend in southwest monsoon and post monsoon seasons. The number of spathes present in the crown was low in 2002-03 and 2004-05 (2.3 palm each).

Table 4.9: Mean monthly spathe present on the crown in different seasons

Season	Summer (Mar-May)	SWM (Jun.-Sept)	PM (Oct.-Nov)	Winter (Dec.-Feb.)	Mean	**Total**
2002-03	2.4	1.4	1.9	3.4	2.3	**9.1**
2003-04	2.8	2.4	2.9	3.2	2.8	**11.3**
2004-05	2.3	1.8	1.9	3.3	2.3	**9.3**
2005-06	2.9	2.6	3.1	3.3	3.0	**11.9**
2006-07	2.9	2.5	2.8	3.3	2.9	**11.5**
Mean	**2.6**	**2.1**	**2.5**	**3.3**	**2.6**	**10.5**

The study revealed that the number of spathes present on the crown and spathe emergence followed the same trend seasonally except their peak appearance during winter and post monsoon, respectively. The number of spathes present on the crown in coconut was maximum in winter due to cumulative effect of high spathe emergence in post monsoon season, followed by winter. As the spathe duration takes about three months, the emergence of spathes during post monsoon season completes its phase only during winter. The low spathe emergence in the southwest monsoon season and previous season (summer) resulted in poor number of spathes during southwest monsoon. The maximum number of spathes present in the crown during winter season can be attributed to the fact that high rainfall 29 months before (June-September) the spathe emergence coincide with the receipt of southwest monsoon rainfall were optimum, which results in better availability of soil moisture. It may favour congenial environment for the primordia initiation and thus maximum spathe emergence during winter season.

The unfavourable weather conditions such as low rainfall, number of rainy days and high temperature coupled with more sunshine hours 29 months prior to the spathe emergence (January- April) would have played a major role in low number of spathe present in the coconut crown during the southwest monsoon season. Maximum temperature recorded during this period was more than 34°C in all the years. Vapour pressure deficit was also very high coinciding with this period in all the years. The amount of rainfall received from January to April was only 73 mm in four rainy days during 2000. Moisture availability in the soil was only 5.4%. It is obvious that the low rainfall was the major factor in low spathe present in crown during southwest monsoon of 2002, 2004 and 2006 (Fig. 4.12).

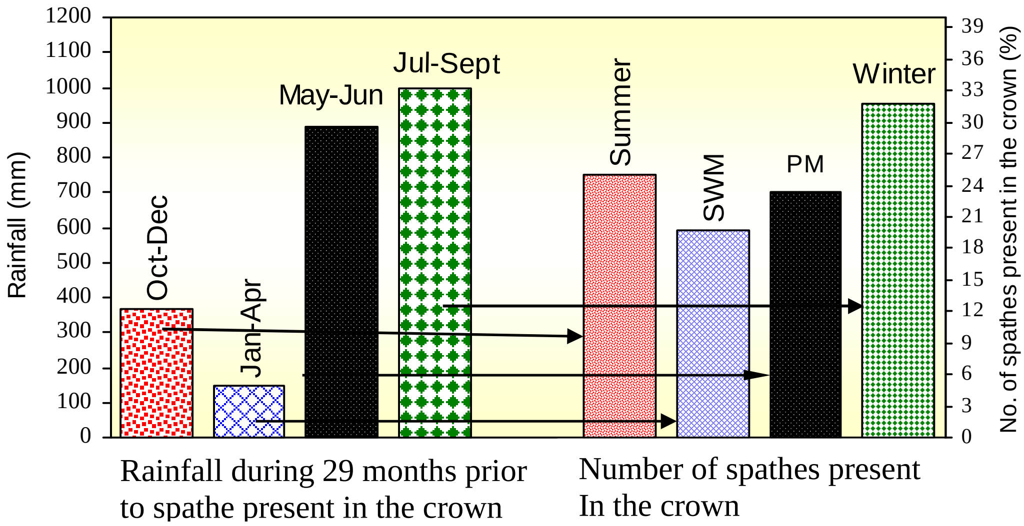


Fig.4.12: Average rainfall during 29 months prior to the spathe present in the crown

The effect of maximum temperature, vapour pressure deficit and soil moisture during 29 months prior to the spathe emergence and mean seasonal variation in spathe emergence shown in Fig. 4.13.

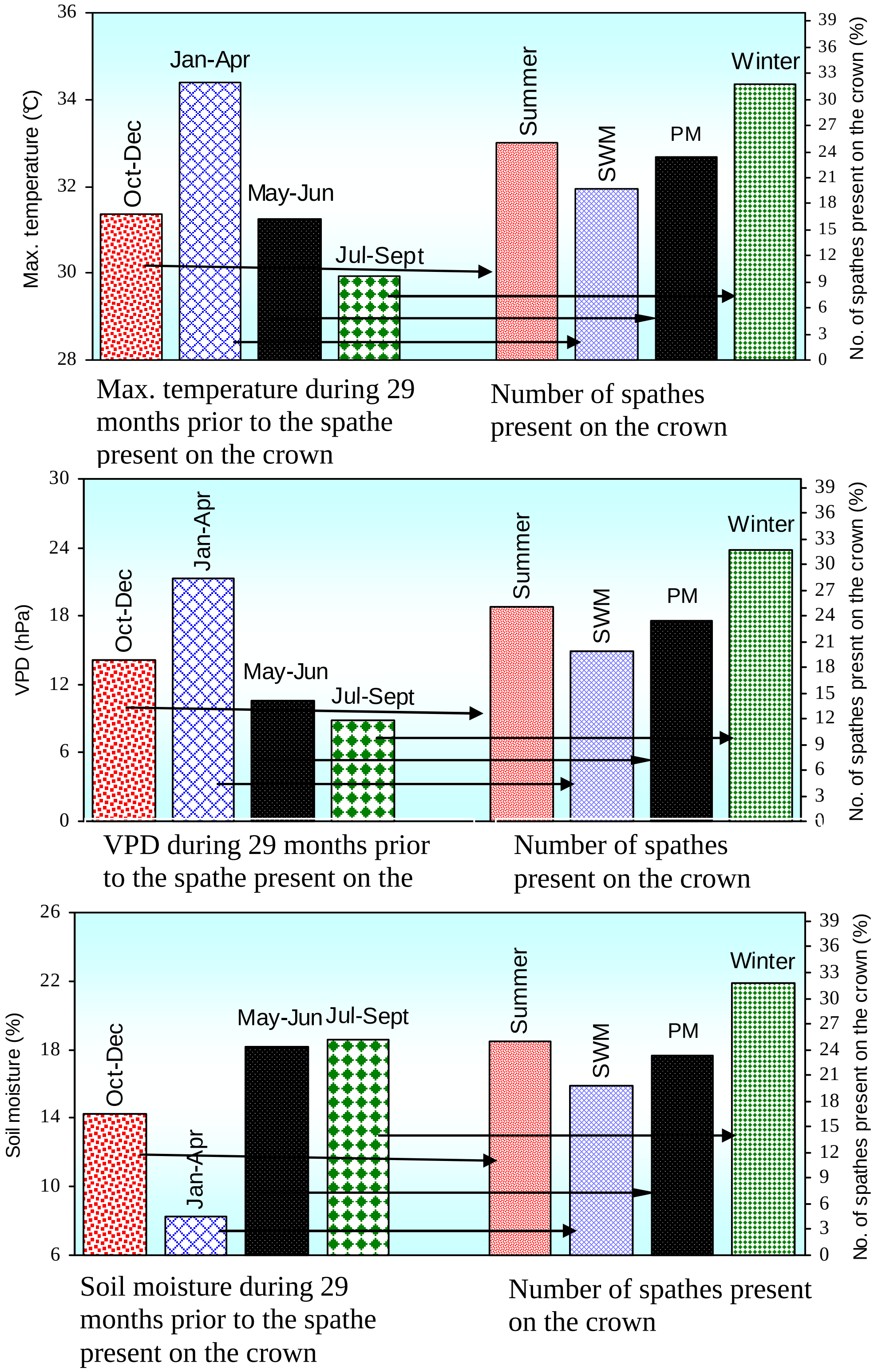


Fig.4.13: Influence of maximum temperature, vapour pressure deficit and soil moisture during 29 months prior to the spathe present in the crown

The temperature, both air and soil, vapour pressure deficit, sunshine and evaporation had negative correlation while rainfall, number of rainy day and soil moisture had positive correlation with spathe present in the crown. The influence of maximum temperature, vapour pressure deficit and soil moisture during 29 months prior to spathe present in the crown and mean seasonal variation in spathe emergence shown in Fig.4.14, Fig.4.15 and Fig.4.16, respectively.

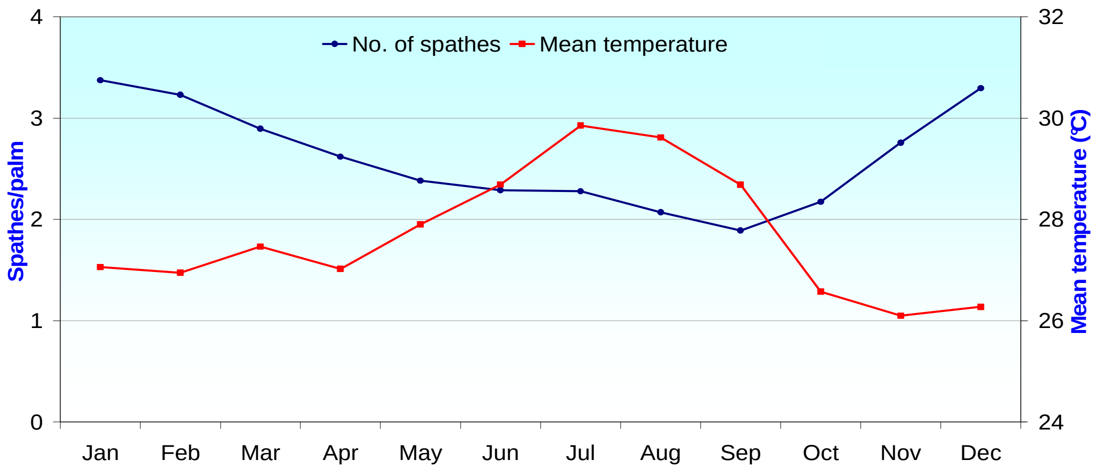


Fig. 4.14: Average temperature during 29 months prior to the spathe present on the crown and mean monthly spathe present on the coconut crown

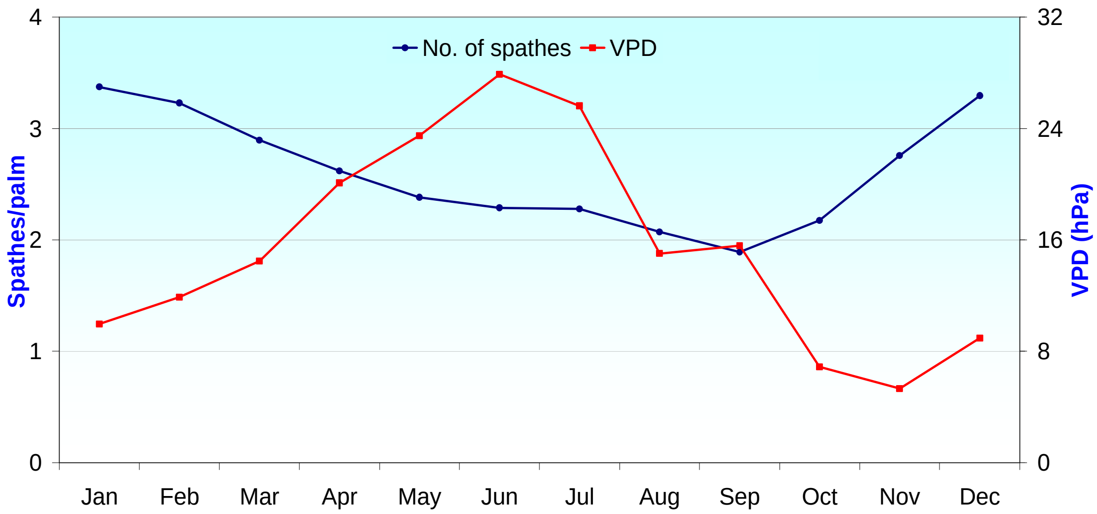


Fig. 4.15: Vapour pressure deficit during 29 months prior to the spathe present on the crown and mean monthly spathe present on the coconut crown

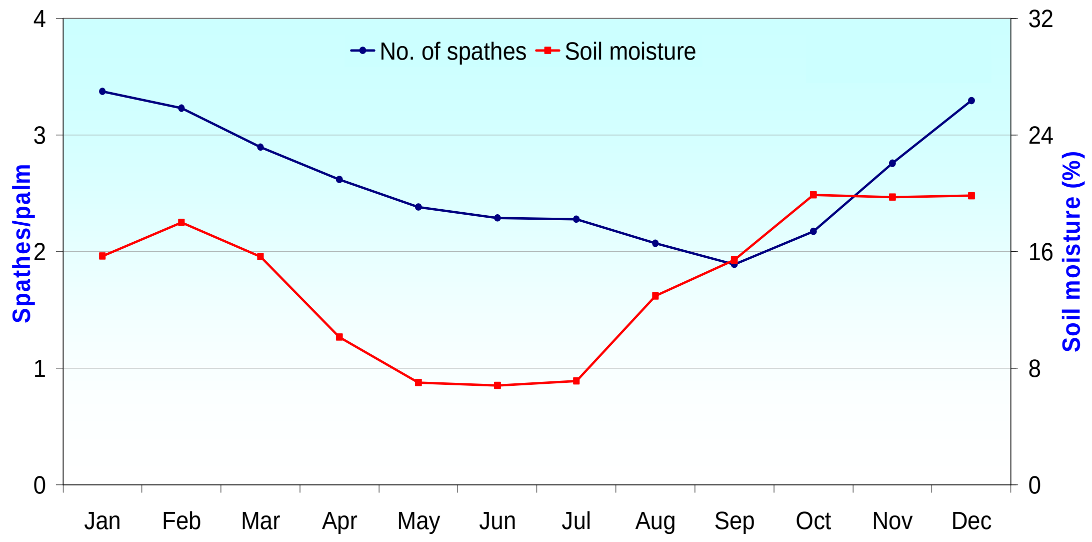


Fig. 4.16: Soil moisture during 29 months prior to the spathe present on the crown and mean monthly spathe present on the coconut crown

4.3.5 Spathe duration in coconut

The number of weeks taken from initiation of spathe at leaf axil to spathe opening (spadix emergence) was high (10.7 weeks) in Kuttiadi while the least (9.3 weeks) in Komadan. On an average, the annual spathe duration was around 10 weeks (Table 4.10).

Table 4.10: Mean seasonal variation in spathe duration in different cultivars of coconut during 2002-2007

Season	Tiptur Tall	Kuttiadi	Komadan	Kasaragod	**Mean**
Summer (Mar-May)	10.9	10.5	9.1	10.8	**10.3**
SWM (Jun.-Sept)	10.0	10.0	8.7	9.5	**9.6**
PM (Oct.-Nov)	10.3	10.9	9.5	10.2	**10.2**
Winter (Dec.-Feb.)	11.1	11.3	9.9	11.3	**10.9**
Mean	**10.6**	**10.7**	**9.3**	**10.5**	**10.3**

The monthly spathe duration was maximum in February (11.3 weeks), followed by March (11.2 weeks), January (10.2 weeks) and December (10.5 weeks). The number of weeks taken from initiation of spathe at leaf axil to spadix emergence

(Table 4.11) was minimum (9.0 weeks each) in June, followed by July (9.3 weeks) and May (9.5 weeks).

Table 4.11: Month-wise spathe duration of different cultivars in coconut

Month	Cultivar				**Mean**
	Tiptur Tall	Kuttiadi	Komadan	Kasaragod	
January	11.0	11.2	9.9	11.4	**10.9**
February	11.6	11.5	10.3	11.7	**11.3**
March	11.8	11.6	9.6	11.6	**11.2**
April	10.7	10.5	9.5	10.7	**10.4**
May	10.3	9.7	8.1	10.1	**9.5**
June	10.4	9.2	7.6	8.8	**9.0**
July	9.6	9.7	8.6	9.5	**9.3**
August	9.7	10.3	9.0	9.5	**9.6**
September	10.0	10.4	9.5	10.2	**10.0**
October	10.4	10.7	9.2	10.0	**10.1**
November	10.1	11.1	9.7	10.2	**10.3**
December	10.7	11.1	9.4	10.9	**10.5**
Mean	**10.6**	**10.7**	**9.3**	**10.5**	**10.3**

It clearly indicated that the number of weeks from the spathe emergence to opening gradually increased from July (9.5 weeks) and reached to its peak (11.3 weeks) in February and thereafter decreased gradually and reached to its low (9.0 weeks) in June. The duration of spathe in all the cultivars was minimum (9.6weeks) if it is emerged in southwest monsoon while maximum (10.9 weeks) in winter, followed by post monsoon (10.2weeks). The spathe duration during summer took more than ten weeks on an average, which was intermediary.

Repeated measures ANOVA indicated that there is significant seasonal influence on the spathe duration ($F (3, 108) = 36.383$ $P < 0.001$). Interaction between season and variety is also significant ($F (9,108) = 2.265$, $P < 0.05$. There is a significant difference between the mean seasonal spathe duration ($F (3, 36) = 21.502$, $P<0.001$). DMRT analysis reveled that mean seasonal spathe duration during southwest monsoon season was significantly different from winter season, post monsoon and summer season. But there is no significant difference in spathe duration between post monsoon and summer seasons. The duration of spathe took 79 days to open when it is emerged in March while it took 63 days if it was emerged in June (Fig.4.17).

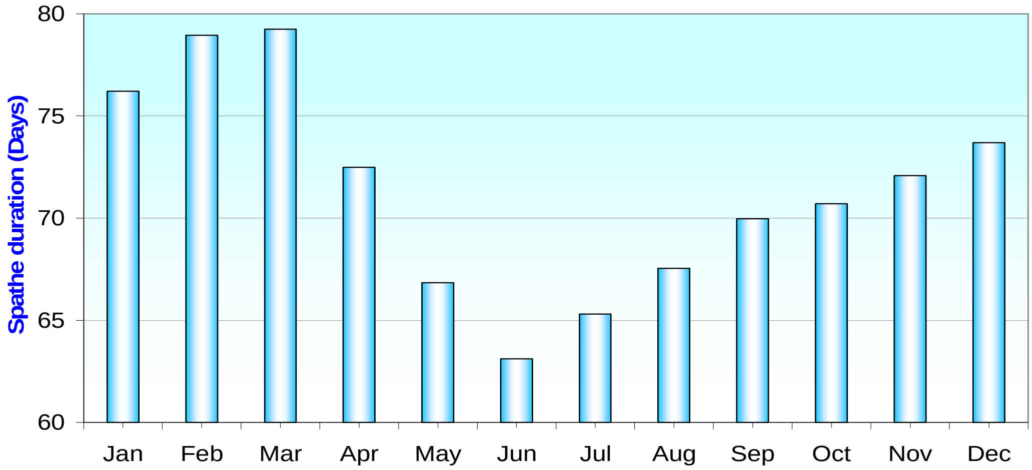


Fig.4.17: Mean monthly spathe duration

4.3.5.1 Effects of weather

The number of weeks taken from initiation of spathe to spathe opening (spadix emergence) from year to year during the study period varied though it is not significant, having maximum (10.4 weeks each) in 2002-03 and 2003-04 and minimum (10.0 weeks) in 2004-05. This was intermediary (10.2 weeks) in 2005-06 and 2006-07. It also revealed that the duration of spathe was less (9.7 weeks) during the post monsoon and winter (10.5 weeks) in 2004-05 when compared to that of the remaining years under the study in respective seasons (Table 4.12).

Table 4.12: Mean spathe duration in coconut (weeks)

Season	Summer (Mar-May)	SWM (Jun.-Sept)	PM (Oct.-Nov)	Winter (Dec.-Feb.)	**Mean**
2002-03	10.1	9.4	10.5	11.5	**10.4**
2003-04	10.6	9.8	10.3	11.0	**10.4**
2004-05	10.3	9.4	9.7	10.5	**10.0**
2005-06	10.2	9.6	10.2	10.8	**10.2**
2006-07	10.3	9.4	10.3	10.8	**10.2**
Mean	**10.3**	**9.6**	**10.2**	**10.9**	**10.3**

The spathe duration was high (11.5 weeks) in winter 2002 - 03 while low (9.4 weeks) in southwest monsoon during 2002-03, 2004-05 and 2006-07.

High rainfall and adequate soil moisture in presence of optimum temperature conditions (a maximum of 29-30°C and minimum of 22 - 24°C) resulted in early opening of spathes. The low spathe duration during southwest monsoon season can be attributed to the high minimum temperature, low temperature range, high vapour pressure, low vapour pressure deficit, high relative humidity, low wind speed, low sunshine hours and low evaporation. In addition to low temperature range, rainfall during southwest monsoon after a prolonged dry spell may stimulate for early break of spathe. These relationships hold good for the other seasons also. That is the reason, why, the duration of spathe took less duration (9.6 weeks) during southwest monsoon season when compared to that of other seasons. Similar weather systems continue to some extent during post and pre monsoon seasons. It resulted in low spathe duration relatively during the post monsoon season (10.2 weeks) and summer (10.3 weeks). The reasons for the maximum spathe duration during winter season can be attributed to low minimum temperature, relative humidity, high temperature range, wind speed, vapour pressure deficit, evaporation and sunshine hours prevailing during winter season when compared to other seasons. These weather conditions during winter led to maximum spathe duration (10.9 weeks). The low (10.0 weeks) spathe duration during 2004-05 is mainly attributed to the well distributed rainfall with adequate soil moisture (Fig. 4.18) along with optimum maximum and minimum temperatures and low vapour pressure deficit (Fig. 4.19). That is, why, spathe took less number of days to open during 2004-05.

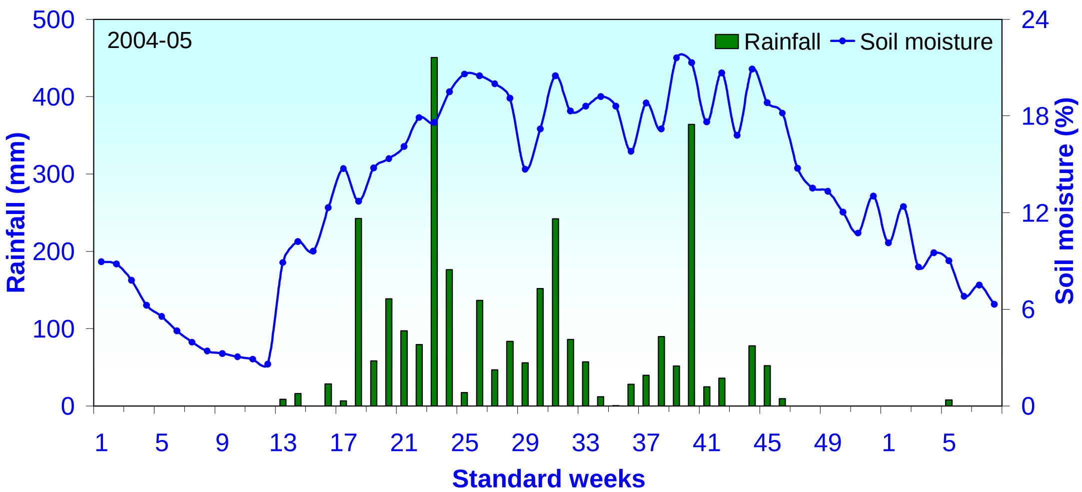


Fig. 4.18: Weekly rainfall (mm) and soil moisture (%) at Vellanikkara during 2004-05 (from 1st January 2004 to 28 February 2005)

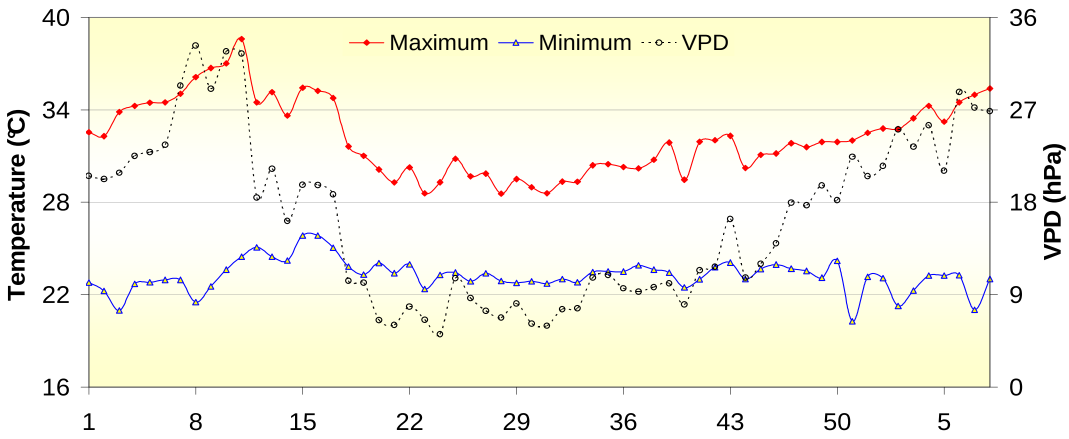


Fig. 4.19: Weekly maximum, minimum temperature and vapour pressure deficit at Vellanikkara during 2004-05 (from 1st January 2004 to 28 February 2005)

The correlations between the weather parameters and spathe duration indicated that minimum temperature, morning soil temperature, soil moisture, rainfall, and number of rainy days had negative correlation (Significant at 0.01 level) while maximum and mean temperature, vapour pressure deficit, evaporation, growing degree days and helio thermal units had positive correlation (Significant at 0.01 level) with spathe duration

4.3.6 Spathe opening / spadix emergence

The coconut inflorescence is enclosed in a double sheath or spathe, the whole structure known as a 'spadix' which is borne singly in the axil of each leaf. In coconut palms that have come to the normal bearing stage, every leaf axil will normally produce an inflorescence (spadix). The spadix formed at middle of the leaf axil never remains on petiole. Larger number of spadices is produced in summer season than the other season. The number of leaves developed as well as the number of spadix production are influenced by cultivars and manuring. The response to manuring on production of spadix is varied for different types of tree, the poor trees responding more than high or the medium yielders. Patel (1938) reported that the growth period of spadix from initiation of primordium to ripening of nuts as 44 months. Critical stages of the development of the spadix have great influence on yield of nuts. Distinct yield variation has been recorded in coconut tracts with high temperature, rainfall, and relative humidity.

4.3.6.1 Varietal and seasonal effects on spadix emergence

The annual number of spadices emerged in Tiptur Tall was high (1.1/palm/month) while the least (0.9/palm/month) in Komadan. It indicated that Tiptur Tall appears to be better among the four cultivars tested in terms of spadix emergence (Table 4.13). On an average, the number of spadices emerged annually was twelve. Interaction between season and variety is not significant (F (9,108) = 1. 224, P> 0.05. It clearly revealed that there is no varietal difference on the spadix emergence in coconut.

Table 4.13: Average number of spadix emergence/palm/month in different seasons from 2002-2007

Season	Tiptur Tall	Kuttiadi	Komadan	Kasaragod	**Mean**
Summer (Mar-May)	1.5	1.3	1.3	1.4	**1.4**
SWM (Jun.-Sept)	1.0	1.0	0.9	0.9	**0.9**
PM (Oct.-Nov)	0.8	0.8	0.8	0.7	**0.8**
Winter (Dec.-Feb.)	1.1	1.1	1.0	1.0	**1.0**
Mean	**1.1**	**1.0**	**0.9**	**1.0**	**1.0**

The monthly spadix emergence was minimum in October (0.7/palm/month), followed by September (0.8/palm/month) while it was maximum (1.5/palm/month each) in March and May (Table 4.14), followed by February and August (1.2/palm/month each).

Table 4.14: Month-wise spadix emergence of different cultivars in coconut

Month	Cultivar				**Mean**
	Tiptur Tall	Kuttiadi	Komadan	Kasaragod	
January	0.8	0.9	1.0	1.0	**0.9**
February	1.2	1.2	1.1	1.2	**1.2**
March	1.7	1.4	1.5	1.4	**1.5**
April	1.1	1.1	1.1	1.2	**1.1**
May	1.6	1.4	1.4	1.6	**1.5**
June	0.9	0.9	0.9	0.9	**0.9**
July	1.1	0.9	0.9	1.0	**1.0**
August	1.3	1.2	1.1	1.1	**1.2**
September	0.9	0.8	0.6	0.7	**0.8**
October	0.7	0.7	0.6	0.6	**0.7**
November	0.8	0.9	1.0	0.8	**0.9**
December	1.0	0.9	0.9	0.8	**0.9**
Mean	**13.1**	**12.3**	**12.1**	**12.3**	**12.5**

It clearly indicated that spadix emergence gradually increased from September to October and reached to its high in summer months (Fig.4.20). The effect of seasonality indicated that the number of spadices emerged was less during post monsoon (0.8/palm/month) and high during summer (1.4/palm/month) when compared to that of southwest monsoon (0.9/palm/month) and winter (1.0/palm/month). The cumulative effect of number of spathes and its duration in the post monsoon and winter seasons led to more spadix production in summer.

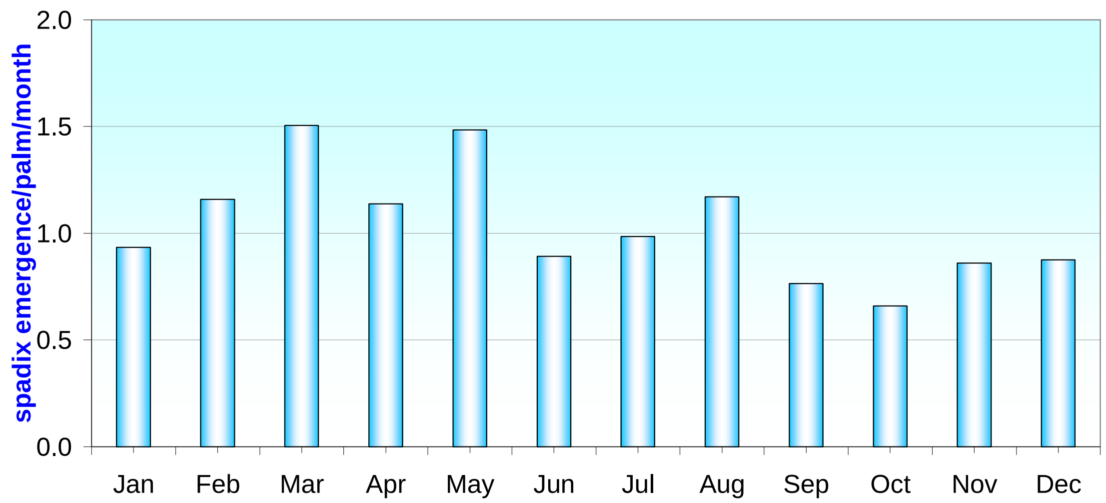


Fig.4.20: Mean monthly spadix emergence in coconut

The weather factors during the primordium initiation (32 month before) may be having benevolent or malevolent effects on spadix production of coconut as the primordium initiation to spadix production takes 32 months.

As a whole, the spadix emergence is maximum (33.9%) during summer in all the cultivars unlike in case of spathe emergence (Fig.4.21). The minimum spadix emergence was during post monsoon season (17.5%). The spadix emergence was intermediary during winter (25.5%) and southwest monsoon seasons (23.1%). All the cultivars followed the similar trend in spadix production.

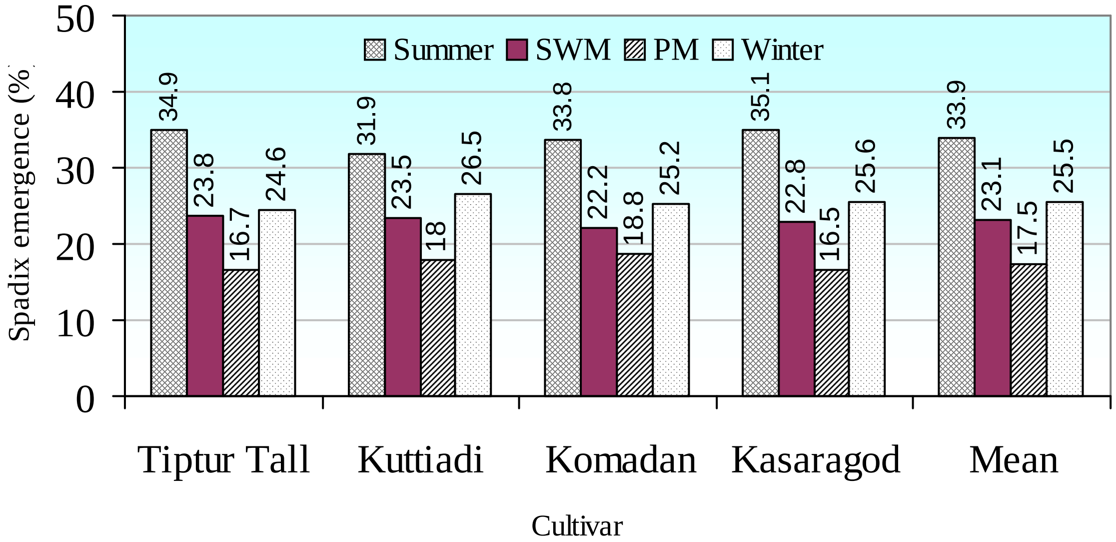


Fig. 4.21: Percentage of spadix emergence during different seasons

The results of the study were in agreement with Marar and Pandalai (1957). They observed that spadix emergence was maximum during summer (March-May) and minimum during post monsoon (October-November), followed by winter (December-January). Same results were obtained by Menon and Pandalai (1958). The above results were in conformity with Bhaskaran and Leela (1983), Sreelatha and Kumaran (1991) and Vanaja and Amma (2002).

4.3.6.2 Effects of Weather

Year to year spadix emergence during the study period varied significantly, having maximum (14.1/palm/year) during 2005-06 and minimum (10.6/palm/year) during 2002-03 and 2004-05 (10.7/palm/year). As a whole, the production of spadix was maximum during summer in all the years tested while low during the post monsoon season (Table 4.15).

Table 4.15: Mean monthly spadix emergence in different seasons

Season	Summer (Mar-May)	SWM (Jun.-Sept)	PM (Oct.-Nov)	Winter (Dec.-Feb.)	Annual
2002-03	3.9	3.2	0.5	3.1	10.6
2003-04	4.4	3.9	2.3	3.1	13.7
2004-05	3.7	3.4	0.8	2.8	10.7
2005-06	4.4	4.2	2.1	3.4	14.1
2006-07	4.3	4.3	2.0	3.1	13.7
Mean	4.1	3.8	1.5	3.1	12.5

The reasons for maximum spadix emergence during summer season can be attributed to the maximum number of spathes present on the crown during winter in which the duration from spathe to spadix was also more. When coconut spathes were exposed to range of higher atmospheric temperature (32-36°C) it may cause for early opening of spathe which is nothing but spadix emergence. The number of spathes present on the crown was less during the southwest monsoon, and hence the opening of spathe during the ensuing post monsoon was less. The same explanation holds good in case of other seasons too. Low spadix production during 2002-03 and 2004-05 was mainly attributed to summer drought during 2002 and 2004. Early withdrawals of northeast monsoon during 2001, absence of winter rain and late commencement of summer showers during 2002 led to less spathe emergence during 2002-03. This resulted less spathe emergence during 2002-03 and thereby less spadix production during 2002-03. Similar was the case noticed during 2003 northeast monsoon, and summer 2004. That is why, the spadix production is less during 2004-05. The maximum number of spadix production during summer season can be attributed to the fact that high rainfall 32 months before the spadix production (July-September) coincide with the receipt of southwest monsoon rainfall were optimum, which results in better availability of soil moisture. It may favour congenial environment for the primordium initiation and thus maximum spadix production during summer season.

The unfavourable weather conditions such as low rainfall, number of rainy days and high temperature coupled with more sunshine hours 32 months prior to the spadix production (February- March) would have played a major role in low number of spadix production during the post monsoon season. Maximum temperature recorded during this period was more than 34.5°C in all the years. Vapour pressure deficit was also very high coinciding with this period in all the years. The amount of rainfall received from February to March was revolving around 4.6 to 16.6 mm in all the years except in 2003. 256.9 mm of rainfall was received during 2003. Average moisture available in the soil was only 7.1 % during that period. It is obvious that the low rainfall was the major factor in low spadix production in coconut during post monsoon season (Fig. 4.22).

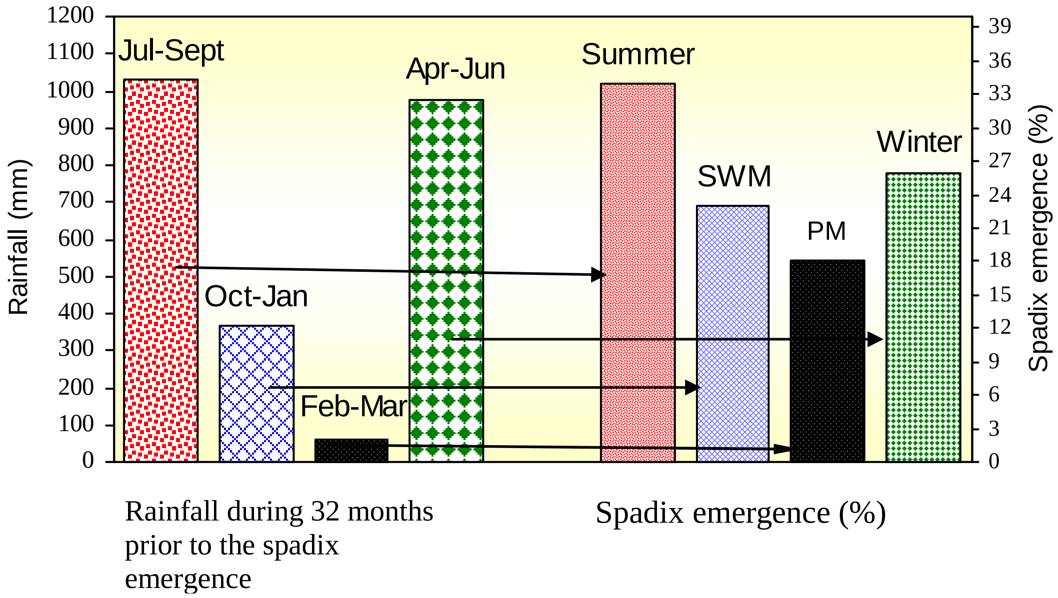


Fig. 4.22: Rainfall during 32 months prior to the spadix emergence

The effect of maximum temperature, vapour pressure deficit and soil moisture during 32 months prior to the spathe emergence and mean seasonal variation in spathe emergence shown in Fig. 4.23.

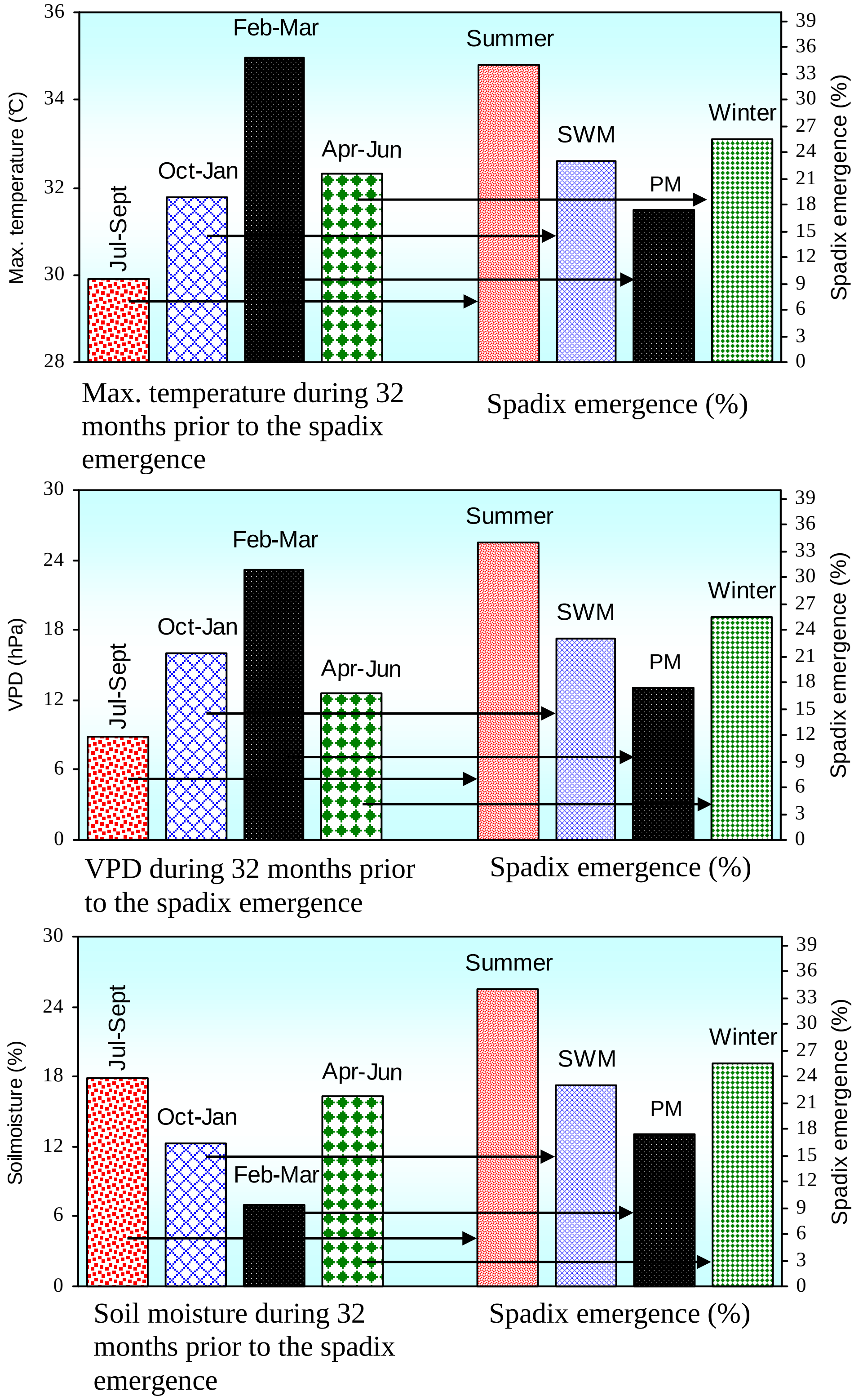
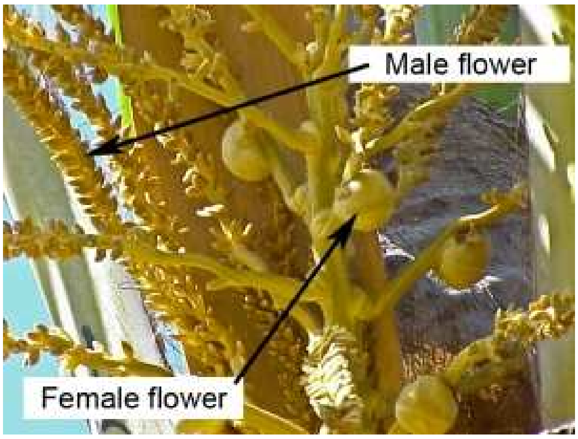


Fig. 4.23: Maximum temperature, Vapour pressure deficit and soil moisture during 32 months prior to the spadix emergence

The temperature, both air and soil, vapour pressure deficit, sunshine and evaporation had negative correlation while rainfall, number of rainy days and soil moisture had positive correlation with spadix production These are the weather factors which influence spadix emergence to a large extent.

4.4 FEMALE FLOWER PRODUCTION

The inflorescences of the coconut are formed in the axils of every leaf of bearing tree. The coconut is a monoccious plant producing male and female flowers separately in the same tree. The flowers are light yellow in color. The female flowers popularly known as the button are globose and sessile. Inflorescence carries both male and female flowers. The male flowers are more numerous than the female flowers. The former are born on the top portion of spikelets which are attached to a main axis or peduncle. The female flowers are situated at the base of the spikelets. The peduncle of the inflorescence bears 30 to 40 braches known as the spikes. In each spike the male and female flowers ranges from 200 to 300. There are also palms which produce either completely male or female flowers. The production of female flowers is an important character as it influences to greater extent the final yield of ripe nuts. The male flowers are the first to open, beginning at the top of each spikelet and proceeding towards the base. After each flower opening, the pollen is shed, and male flowers abscise, the whole process taking just a day. The male phase, however, takes about 20 days in majority palms but this may vary according to season and variety. A female flower remains receptive from 1



to 3 days. Depending on the environmental conditions and variety, the female phase may begin a few days or later after the spathe has opened and lasts 3-5 days in tall palms and about 8-15 days in dwarfs. A normal inflorescence may have 10-50 female flowers. With natural pollination, 50-70% usually abort and fall off, especially those which emerge during severe dry weather. The remaining flowers develop into fruits, which take about 12 months to mature.

4.4.1 Varietal and seasonal effects

The number female flowers was high (41.5/bunch) in Tiptur Tall while low (30.1/bunch) in Kuttiadi (Table 4.16). It indicated that Tiptur Tall appears to be better among the four cultivars tested in terms of female flower produced. On an average, the number of female flowers produced per bunch was thirty four. However, there was a variation in the number of female flowers produced seasonally.

Table 4.16: Female flower production per bunch in different coconut cultivars during 2002-2007

Season	Tiptur Tall	Kuttiadi	Komadan	Kasaragod	**Mean**
Summer (Mar-May)	54.7	43.1	47.1	44.0	**47.2**
SWM (Jun.-Sept)	41.1	25.2	29.4	29.1	**31.2**
PM (Oct.-Nov)	30.6	16.4	18.3	23.2	**22.1**
Winter (Dec.-Feb.)	39.6	35.8	36.8	31.9	**36.0**
Mean	**41.5**	**30.1**	**32.9**	**32.0**	**34.1**

The number of female flowers produced during the summer was high (47.2/bunch) while minimum number of female flowers (only 22/bunch) during the post monsoon season (October-November). A gradual decline in female flower production was noticed from summer to post monsoon season and thereafter an increase was noticed during winter in all the cultivars. It revealed that the trend in female flower production was uniform in all the months despite the varietal difference (Fig. 4.24).

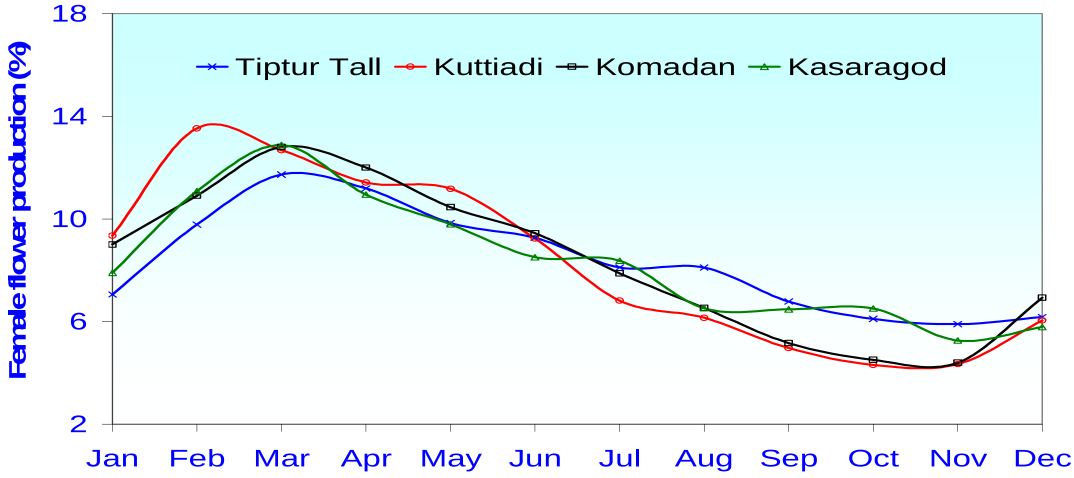


Fig. 4.24: Monthly percentage of female flower production

When the monthly female flower production is considered, it was maximum (51.8/bunch) in March, followed by April (47.2/bunch), February (46.4/bunch) and May (42.8/bunch) while it was minimum (20.6/bunch) in November, followed by October (21.9/bunch) and 24.3/bunch in September (Table 4.17).

Table 4.17: Month-wise female flower production (No./bunch) of different cultivars in coconut

Month	Cultivar				**Mean**
	Tiptur Tall	Kuttiadi	Komadan	Kasaragod	
January	35.9	33.4	37.0	31.1	**34.6**
February	48.8	44.3	42.8	43.7	**46.4**
March	56.7	49.0	51.6	50.7	**51.8**
April	56.0	43.3	47.3	42.1	**47.2**
May	50.1	38.3	42.0	38.6	**42.8**
June	44.2	32.8	36.8	33.5	**37.4**
July	41.3	24.8	30.4	30.1	**31.7**
August	41.3	21.3	24.8	25.7	**28.5**
September	33.5	18.8	21.2	23.5	**24.3**
October	31.1	16.3	18.5	21.6	**21.9**
November	28.0	16.4	17.1	20.7	**20.6**
December	31.4	21.9	25.5	22.8	**25.7**
Mean	**41.5**	**30.1**	**32.9**	**32.0**	**34.1**

It was intermediary during rainy months from June to August (28.5 - 37.4/bunch). It clearly indicated that the number of female flowers gradually increased from

December (25.7/bunch) and reached to its peak (51.8/bunch) in March and thereafter decreased gradually and reached to its low (21.6/bunch) in November. The number of female flowers produced monthly is illustrated in Fig. 4.25.

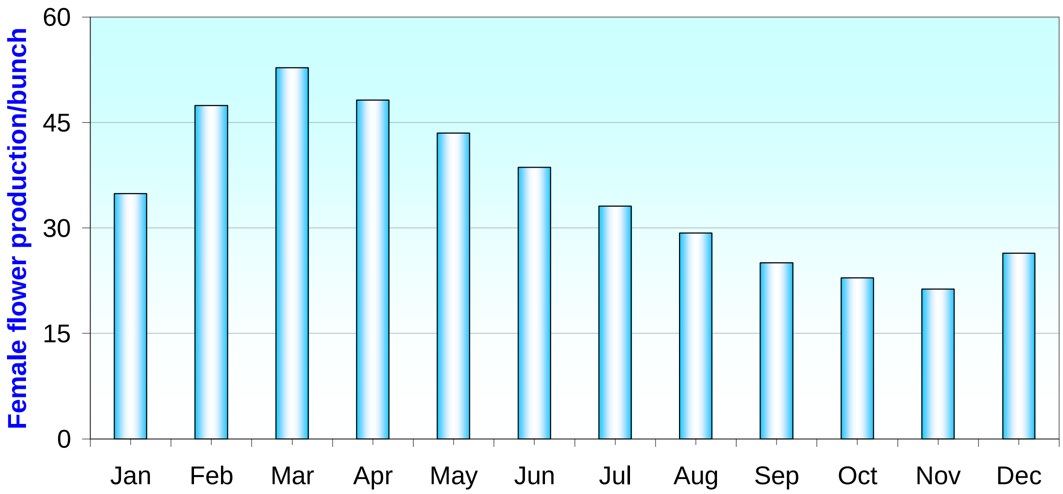


Fig. 4.25: Mean monthly female flower production in coconut

4.4.2 Effects of weather

Year to year female flower production during the study period varied significantly, having maximum (44.7/bunch) during 2005-06 and minimum (23.3/bunch) during 2002-03. As a whole, the female flower production was maximum (47.2/bunch) during summer season in all the years tested while low during post monsoon (22.1/bunch) except 2003 - 04 (Table 4.18).

Table 4.18: Mean monthly female flower production in different seasons

Season	Summer (Mar-May)	SWM (Jun.-Sept)	PM (Oct.-Nov)	Winter (Dec.-Feb.)	**Total**
2002-03	37.4	18.6	7.1	29.9	**23.3**
2003-04	49.7	26.9	27.5	32.0	**34.0**
2004-05	40.1	28.3	15.8	38.4	**30.6**
2005-06	58.4	46.2	33.6	40.5	**44.7**
2006-07	50.6	35.9	26.4	39.3	**38.0**
Mean	**47.2**	**31.2**	**22.1**	**36.0**	**34.1**

The number of female flower production was low in 2002-03 (23.3/bunch), and 2004-05 (30.6/bunch). Decline in female flower production was maximum (31.7%) during 2002-03 followed by 2004-05 (10.3%). It was mainly attributed to prolonged dry spell from November to April, which led to summer drought during 2002-03 and 2004-05. It clearly indicated that whenever the summer drought was noticed, decline in female flower production was also noticed, varying between 10 and 30% depending upon the severity of drought (Table 4.19).

Table 4.19: Percentage deviation of female flower production from mean in different seasons

Season	Summer (Mar-May)	SWM (Jun.-Sept)	PM (Oct.-Nov)	Winter (Dec.-Feb.)	**Total**
2002-03	-20.8	-40.4	-67.9	-16.9	**-31.7**
2003-04	5.3	-13.8	24.4	-11.1	**-0.3**
2004-05	-15.0	-9.3	-28.5	6.7	**-10.3**
2005-06	23.7	48.1	52.0	12.5	**31.1**
2006-07	7.2	15.1	19.5	9.2	**11.4**

4.4.2.1 Influence of dry spell during the critical stages in female flower production

The number of female flowers produced during the summer months was high when compared to that of other seasons. It could be attributed to less number of dry spells experienced during the primordium initiation and ovary development stages. The total duration of dry spell varied from16 to 22 weeks in four critical stages of coconut resulting to high number of female flower production during summer season (Table 4.20). In contrast, the total duration of dry spell varied from 30 to 36 weeks in four critical stages of coconut, resulting to low number of female flower production during southwest monsoon season. The female flower production was intermediary in winter. Though the total duration of dry spell (15-18 weeks) was similar as in the case of summer, long dry spell (11.2 weeks) a year ahead of female flower production resulted in intermediary female flower production during winter (Table 4.21).

Table 4.20: Influence of dry spells during the critical stages in female flower production

Year	Season	No. of dry week during critical stages (Lag period in months)				Total No. of dry weeks	Seasonal female flower production
		32	16	11-12	6-7		
2002	Summer	3	10	7	2	22	37.4
	Southwest monsoon	11	10	1	14	36	18.6
	Post monsoon	7	0	3	3	13	7.1
	Winter	3	2	12	1	18	29.9
2003	Summer	1	10	4	2	17	49.7
	Southwest monsoon	10	8	2	10	30	26.9
	Post monsoon	8	0	1	3	12	27.5
	Winter	2	2	9	3	16	32.0
2004	Summer	1	9	6	1	17	40.1
	South west monsoon	11	7	1	15	34	28.3
	Post monsoon	6	0	4	6	16	15.8
	Winter	2	1	11	1	15	38.4
2005	Summer	2	12	7	1	22	58.4
	South west monsoon	9	10	1	16	36	46.2
	Post monsoon	3	0	4	3	10	33.6
	Winter	4	1	12	1	18	40.5
2006	Summer	1	12	4	2	19	50.6
	South west monsoon	12	8	2	13	35	35.9
	Post monsoon	8	0	1	3	12	26.4
	Winter	2	2	12	1	17	39.3
2007	Summer 2007	1	9	4	2	16	52.7

The least female flower production during the post monsoon season could be attributed due to heavy rainfall, leading to waterlogging during the branch development stage in addition to dry spell during primordium initiation and ovary development stages in coconut. It revealed that the duration of dry spell and wet spell during four critical phases of coconut decides the production of female flowers in addition to variety and better management practices under rainfed conditions.

Table 4.21: Influence of mean dry spell (%) during the critical stages in coconut and female flower production from 2002 to 2006

Season	Mean dry week (%) (Lag periods in months)				Mean seasonal female flower production
	32 months	16 months	11-12months	6-7months	
Summer	1.5	10.3	5.3	1.7	47.2
Southwest monsoon	10.6	8.6	1.4	13.6	31.2
Post monsoon	6.4	0.0	2.6	3.6	22.1
Winter	2.6	1.6	11.2	1.4	36.0

4.4.2.2 Influence of rainfall during the critical stages in female flower production

The female flower production was high during summer as the coconut palm receives high rainfall during primordium and ovary development stages. It is also observed that rainfall during the branch development stage of inflorescence is comparatively less in all the years. This favours high monthly female production ranges from 37.4 to 58.4/bunch (Table 4.22).

Table 4.22: Influence of rainfall during the critical stages in female flower production

Year	Season	Amount of rainfall received on critical stages (Lag periods in months)				Total rainfall (mm)	Seasonal female flower production
		32	16	11-12	6-7		
2002	Summer	1125.8	49.3	440.1	677.7	2292.9	37.4
	Southwest monsoon	501.3	452.3	1616.2	116.2	2686.0	18.6
	Post monsoon	4.6	1153.9	331.6	67.1	1557.2	7.1
	Winter	808.5	677.7	0.0	1196.1	2682.3	29.9
2003	Summer	1049.8	116.2	375.5	1018.3	2559.8	49.7
	Southwest monsoon	311.5	375.5	1518.3	184.2	2389.5	26.9
	Post monsoon	16.6	887.7	409.8	118.6	1432.7	27.5
	Winter	1111.9	1018.3	162.1	1103.5	3395.8	32.0
2004	Summer	940.0	22.1	158.9	820.6	1941.6	40.1
	South west monsoon	331.6	321.0	1607.0	18.2	2277.8	28.3
	Post monsoon	16.3	1063.2	295.0	68.8	1443.3	15.8
	Winter	892.7	820.6	0.0	1733.9	3447.2	38.4
2005	Summer	984.8	18.2	647.1	1088.0	2738.1	58.4
	South west monsoon	409.8	647.1	1751.3	79.3	2887.5	46.2
	Post monsoon	256.9	1155.6	564.0	171.4	2147.9	33.6
	Winter	634.7	1088.0	7.6	1528.1	3258.4	40.5
2006	Summer	1036.4	79.3	260.6	941.0	2317.3	50.6
	South west monsoon	295.0	260.6	2201.5	14.8	2771.9	35.9
	Post monsoon	8.6	1438.9	190.0	181.4	1818.9	26.4
	Winter	1424.5	941.0	3.2	1803.1	4171.8	39.3
2007	Summer 2007	965.3	14.8	856.9	1396.5	3233.5	52.7

The number of female flowers produced during the southwest monsoon experienced low rainfall during the primordium initiation stage and ovary development stage and high rainfall during male and female flower development stages. Low rainfall during primordium and ovary development stages has detrimental to female flower production. That is why, the female flower produced during southwest monsoon season was comparatively lesser than summer season (female flower ranged from 18.6 to 46.2/bunch). The mean monthly female flower produced during the post monsoon 2002 was only 7.1/bunch and rainfall received during the primordium initiation stage and ovary development stages was only 4.6 mm and 67.1 mm, respectively. The same trend is prevailed during 2004 also. It revealed the importance of rainfall during the primordium and ovary development stage for the female flower production. During the post monsoon 2005, female flowers produced were comparatively high (33.6 nuts). It was mainly attributed to comparatively good amount of rainfall received during the primordium initiation stage (256.9mm) and ovary development stage (171.4 mm). In winter season, intermediary female flower production was noticed during (40.5/bunch) 2006-07. It was 40.5/bunch during 2005-06 and 39.3/bunch in 2006-07 while low (29.9/bunch) during winter 2002-03. The female flowers produced during winter 2005-06 experienced good amount of rainfall (636.4 mm) during primordium initiation, branch development (1088.0 mm) and ovary development stage (1528.1 mm). But the rainfall received during the male and female development stages was only 7.6 mm. It followed the same trend during 2006-07 also. That is why, the winter 2005-06 and 2006-07 recorded high female flowers during the study period. The low female flower production during winter 2002-03 is mainly attributed to comparatively low rainfall (677.7 mm) during branch development stage among the study period.

As a whole, the female flower production is high when rainfall during the formation of primordium and ovary development stages is high and rainfall during the branch development stage is low (Table 4.23). Low rainfall during the primordium initiation and ovary development stages and high rainfall during branch development stage were detrimental to female flower production. Low female flower production during the post monsoon season is mainly attributed to the abotic factors. Thus, it is understood that rainfall during the primordial initiation and ovary development are most crucial for the female flower production

Table 4.23: Influence of mean rainfall during the critical stages in coconut and female flower production from 2002 to 2006

Season	Amount of rainfall received on critical stages (Lag periods in months)				Mean seasonal female flower production
	32 months	16 months	11-12months	6-7months	
Summer	1027.4	57.0	376.4	909.1	47.2
Southwest monsoon	369.8	411.3	1738.9	82.5	31.2
Post monsoon	60.6	1139.9	358.1	121.5	22.1
Winter	974.5	909.1	34.6	1472.9	36.0

4.4.2.3 Influence of soil moisture during the critical stage in female flower production

The female flowers produced during summer experienced comparatively high soil moisture during primordium and initiation and ovary development stages and low soil moisture during branch development stages. The mean soil moisture ranged from 16.4 to13.5% (Table 4.24) during summer, coinciding with primordium initiation and ovary development stages.

Table 4.24: Influence of soil moisture during the critical stages in female flower production

Year	Season	Soil moisture(%) during the critical stages (Lag periods in months)				Mean soil moisture (%)	Seasonal female flower production
		32	16	11-12	6-7		
2002	Summer	15.2	9.5	12.5	16.9	13.5	37.4
	Southwest monsoon	9.6	11.6	18.9	11.7	13.0	18.6
	Post monsoon	3.0	20.8	17.4	6.5	11.9	7.1
	Winter	14.7	16.9	9.6	19.8	15.3	29.9
2003	Summer	17.5	13.4	10.7	18.4	15.0	49.7
	Southwest monsoon	11.7	9.6	19.1	10.1	12.6	26.9
	Post monsoon	8.2	20.2	17.1	18.5	16.0	27.5
	Winter	17.1	18.4	8.6	19.3	15.9	32.0
2004	Summer	18.1	9.8	18.4	19.2	16.4	40.1
	South west monsoon	14.3	16.6	19.7	10.2	15.2	28.3
	Post monsoon	5.7	19.8	17.5	7.3	12.6	15.8
	Winter	15.7	19.2	8.1	17.6	15.2	38.4
2005	Summer	18.8	12.2	10.0	18.9	15.0	58.4
	South west monsoon	12.2	8.6	18.7	11.8	12.8	46.2
	Post monsoon	14.7	18.6	18.2	10.1	15.4	33.6
	Winter	18.7	18.9	9.9	16.9	16.1	40.5
2006	Summer	19.9	13.2	10.6	19.4	15.8	50.6
	South west monsoon	13.8	9.8	20.1	10.4	13.5	35.9
	Post monsoon	3.7	19.7	16.1	10.5	12.5	26.4
	Winter	15.5	19.4	8.8	18.2	15.5	39.3
2007	Summer 2007	18.4	11.4	11.7	18.9	15.1	52.7

The number of female flowers during the southwest monsoon was low (18.6/bunch) in 2002 when compared to that of 2003 (26.9/bunch), 2004 (28.3/bunch), 2005 (46.2/bunch), 2006 (35.9/bunch). The number of female flowers produced during the post monsoon season was also low (7.1/bunch) in 2002 when compared to that of 2003 (27.5/bunch), 2004 (15.8/bunch), 2005 (33.6/bunch) and 2006 (26.4/bunch). It was attributed to low soil moisture that prevailed during primordium initiation and ovary development stages. The coconut palm experienced low soil moisture during primordium initiation stage (3%) and ovary development (6.5%) and highest (20.8%) during branch development stage and male and female development stage (17.8%) in 2002, resulting to low female flower production in post monsoon season. Similar was the case in southwest monsoon also. Therefore, it revealed that low soil moisture during the primordium initiation and ovary development stage detrimental to female flower production.

Table 4.25: Influence of soil moisture during the critical stages in coconut and female flower production from 2002 to 2006

Season	Soil moisture(%) during the critical stages (Lag periods in months)				Mean seasonal female flower production
	32 months	16 months	11-12months	6-7months	
Summer	17.9	11.6	12.4	18.6	47.2
Southwest monsoon	12.3	11.2	19.3	10.8	31.2
Post monsoon	7.1	19.8	17.3	10.6	22.1
Winter	16.3	18.6	9.0	18.4	36.0

As a whole, the coconut palm requires high soil moisture during primordium initiation and ovary development stages and moderate soil moisture during male and female development stages (Table 4.25). Less soil moisture during the primordium initiation and ovary development stages and high (excess) soil moisture during branch development stages and male and female development stages favour low female flower production in post monsoon season. Therefore, the availability of adequate soil moisture during primordial initiation and ovary development is most crucial for better production of female flowers.

4.4.2.4 Influence of weather during the critical stages

To study the association between the weather variables and number of female flowers produced, correlations were worked out in two critical stages viz., primordia initiation and ovary development as these biotic phases are vital for final female flower production. These above phases coincide with 32 months and 6-7 months, respectively prior to the spadix emergence.

Both, air and soil temperature, vapour pressure deficit, wind speed sunshine and evaporation during the primordium initiation of coconut had significant negative correlation with the female flower production while rainfall, number of rainy days and soil moisture influenced positively. The minimum temperature, soil moisture, rainfall and rainy days during the development of branches of inflorescence of coconut had significant negative correlation with the female flower production while vapour pressure deficit, wind speed, sunshine and evaporation influenced positively. Both, air and soil temperature, vapour pressure deficit, wind speed, sunshine and evaporation during the male and female flower development stages (11-12 months prior to the spadix emergence) of coconut had significant positive correlation with the female flower production while soil moisture influenced negatively. The primordium initiation stage and ovary development phases showed similar relationship. However, the minimum temperature had no influence on number of female flowers though negative correlation was seen between them during the primordium initiation. At the same time, the minimum temperature during the ovary development influenced the number of female flowers in coconut.

4.4.3 Estimation of female flower production using weather variables during the critical stages

The pooled data of weather variables during the primordium initiation (32 months before the opening of the inflorescence), development of branches of inflorescence stage (16 months prior to the spadix emergence), male and female flower development stages (11-12 months prior to the spadix emergence) and at the ovary development stage (6-7 months before the opening of the inflorescence) was subjected to principal component analysis. It indicated that mean vapour pressure deficit during the ovary development stage alone accounts for 40.5% of variance. Number of rainy days during the branch development of inflorescence accounts 29.8%, minimum temperature during the male and female flower development stage, accounting for 7%, wind speed at primordial stage accounts for 5.8%, evaporation during the branch development stage accounts for 3.5% and evaporation during male and female flower development stages account for 2.3% of variance. Thus, these weather variables together explain for 88.9% of variance. The linear regression equation developed based on these monthly weather variables at various critical stages and monthly female flower production is as follows.

$Y = -2.201*X_1-0.353*X_2+2.746*X_3 +2.095*X_4 + 0.026*X_5 +0.000068*X_6 -18.474$

Where Y = Number of female flower, X_1 = Mean vapour pressure deficit during the ovary development stage, X_2 = Number of rainy days during the branch development of inflorescence, X_3 = Minimum temperature during the male and female flower development stage, X_4 = Wind speed during primordium initiation stage, X_5 = Evaporation during branch development savage and X_6 = Evaporation at male and female development stage. The equation is significant at 0.01% level ($F (6, 62) = 11.073$, $P<0.001$).

4.4.4 Button shedding in coconut

Shedding of buttons is one of the major constraints in coconut production. Shedding of button nuts and immature nut fall are key factors in determining the final yield of coconut palm. The female flowers often shed down at various stages of development on the spike. This is one of the serious problems faced by the coconut farmers. A coconut inflorescence carries on an average 16-20 female flowers (potential nuts) when the spathe opens. Those female flowers which miss the opportunity of getting fertilized, wither, get detached from the spike and shed in the course of 30 to 45 days. Many research workers have put forth varied reasons for the shedding of female flowers. The salient among them is that the shed female flowers when examined had their ovules already aborted. They formed major portion of the shed female flowers. At times the female flowers known as button are known to shed even after fertilization. Button shedding has also been attributed to the formation of bisexual flowers. The well developed among them get fertilized and develop into normal nuts, while others mostly wither and shed down. The possible causes of nut shedding are fungus or pest attack, nutritional deficiencies, defective pollination and weather conditions. High temperature and rainfall, waterlogging, lack of aeration, severe drought, attack of pest and diseases and sudden changes in the soil pH are attributed as reasons for shedding of fertilized flowers. Bai *et al.,* (2003) reported that button shedding have two peaks in all the varieties, one during summer month and other during monsoon. The study also indicated that shedding of buttons is directly related to the number of female flower production. Keeping the above in view, an attempt has been made to understand the seasonal influence on button shedding in four coconut cultivars tested and analysed the weather effects on button shedding in coconut. The results are summarized below.

4.4.4.1 Varietal and seasonal effects

The mean annual button shedding was high (68.4%) in Kuttiadi while the least (64.5%) in Kasaragod (Table 4.26). It indicated that Kuttiadi was more prone to button shedding when compared to other cultivars tested during the study period. On an average, the mean annual percentage of button shedding was 66.4%.

Table 4.26: Mean button shedding in different cultivars of coconut from 2002 to 2007

Season	Tiptur Tall	Kuttiadi	Komadan	Kasaragod	**Mean**
Summer (Mar-May)	71.2	71.2	69.0	66.1	**69.4**
SWM (Jun.-Sept)	61.9	59.9	65.8	58.4	**61.5**
PM (Oct.-Nov)	60.5	63.3	57.3	63.3	**61.1**
Winter (Dec.-Feb.)	74.7	79.1	70.4	70.3	**73.6**
Mean	**67.1**	**68.4**	**65.6**	**64.5**	**66.4**

The seasonal effect indicated that the button shedding was maximum (73.6%) during winter (December- February), followed by summer (69.4%) while low during southwest monsoon (61.5%) , post monsoon season (61.1%) indicating that there is no significant variation between post monsoon and southwest monsoon seasons in button shedding. However, repeated measures ANOVA indicated that there is a significant seasonal influence on the button shedding in coconut ($F (3, 108) = 89.224$ $P < 0.001$). Moreover Interaction between season and variety is also significant ($F (9,108) = 4.257$, $P< 0.001$. There is a significant difference in the mean on seasonal button shedding in coconut ($F (3, 36) = 28.339$, $P<0.001$). DMRT analysis revealed that the mean button shedding during summer and winter was significantly different from post monsoon and southwest monsoon. But there is no evidence of difference in seasonal mean button shedding during post monsoon and southwest monsoon.

The monthly button shedding was minimum (58.5 %) in August, followed by November (59.4 %), September (60.3 %), July (62%) and October (62.8 %) while it was maximum (74.7 %) in January, followed by February (74.3 %) and 72.2 % in March (Table 4.27).

Table 4.27: Month-wise button shedding (%) of different cultivars in coconut

Month	Cultivar				**Mean**
	Tiptur Tall	Kuttiadi	Komadan	Kasaragod	
January	74.7	81.1	71.6	71.4	**74.7**
February	75.0	79.5	72.8	69.9	**74.3**
March	72.1	76.1	71.3	69.6	**72.2**
April	74.4	71.4	68.1	64.1	**69.5**
May	67.1	66.4	67.4	64.8	**66.4**
June	68.1	63.2	69.6	59.5	**65.1**
July	58.7	61.4	69.7	58.4	**62.0**
August	58.9	55.2	61.2	58.5	**58.5**
September	61.8	59.9	62.3	57.3	**60.3**
October	60.5	63.2	59.0	68.7	**62.8**
November	60.4	63.5	55.6	57.8	**59.4**
December	73.6	75.1	66.5	69.6	**71.2**
Mean	**67.1**	**68.4**	**65.6**	**64.5**	**66.4**

It clearly indicated that the monthly button shedding was gradually decreasing from January (74.7%) to its lowest (58.5%) in August and thereafter increasing gradually and reaches to its peak in January (Fig. 4.26). The study also revealed that the button shedding in coconut was high from December to February during the winter season, followed by March, April and May in summer. The button shedding was minimum from June to November. All the four cultivars followed the similar trend in seasonal t button shedding in coconut.

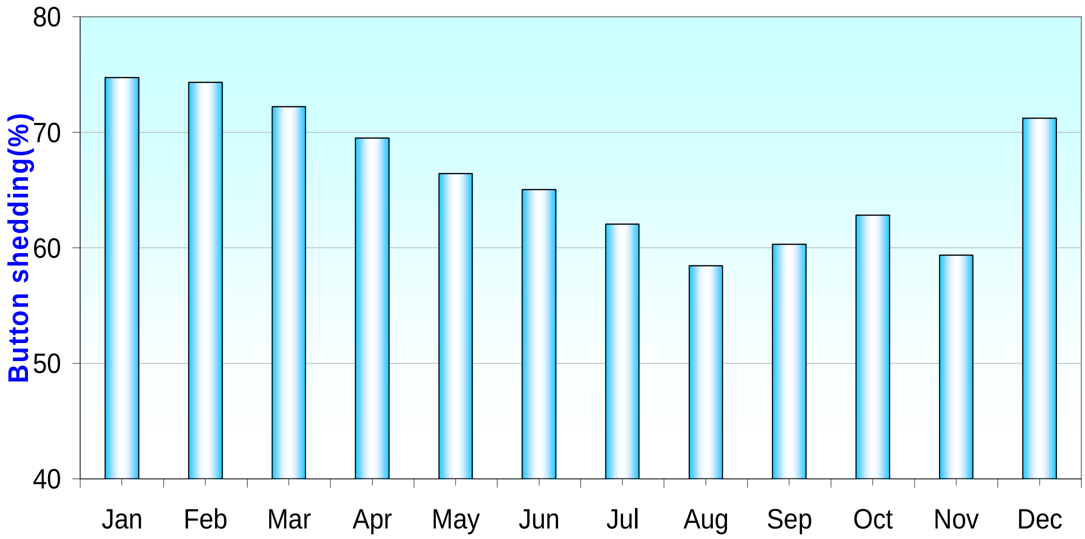


Fig. 4.26: Mean monthly button shedding in coconut

4.4.4.2 Effects of weather

The button shedding was maximum (70.8%) in 2005-06 and minimum (55.2%) during 2002-03. The seasonal button shedding was the highest (81.1%) in winter 2003-04 while lowest (44.6%) in post monsoon season during 2002-03 (Table 4.28).

Table 4.28: Mean button shedding in different seasons

Season	Summer (Mar-May)	SWM (Jun.-Sept)	PM (Oct.-Nov)	Winter (Dec.-Feb.)	**Total**
2002-03	62.5	50.4	44.6	63.4	**55.2**
2003-04	67.6	49.8	66.2	81.0	**66.2**
2004-05	75.4	69.3	60.7	73.0	**69.6**
2005-06	66.1	68.2	65.0	76.0	**68.8**
2006-07	70.2	69.5	68.9	74.6	**70.8**
Mean	**69.4**	**61.5**	**61.1**	**73.6**	**66.4**

As a whole, the button shedding was maximum (73.6%) during winter season in all the years tested except in 2004-05 in which it was observed in summer 2004 (75.4%). It was mainly attributed to the prolonged dry spell from 1st November, 2003 to 28th March 2004. The second maximum (69.4%) button shedding was noticed in summer. The percentage of button shedding was intermediary (61.5%) during southwest monsoon and post monsoon (61.1%).

An attempt was made to work out cause-effect-relationship through correlations between the button shedding and weather variables. The result indicated that temperature of both air and soil, vapour pressure deficit and the Growing Degree Days (GDD) had significant (0.01 level) positive correlations while soil moisture had significant (0.01 level) negative correlation with button shedding in coconut. It revealed that the button shedding is high when the temperature and vapour pressure deficit were high under the soil moisture stress conditions. It also revealed that the button shedding is high when the GDD were high. It could be attributed to the relationships that existed between the temperature and button shedding. All the cultivars tested during the study period showed the similar trend (Fig. 4.27), as the button shedding was high from December to May while low from June to November. The same trend is followed in the case of female flowers. It is obvious that the button shedding is likely to be more if the number of female flowers is more. The abiotic factors that are involved in the case of button shedding are temperature, vapour pressure deficit and soil moisture deficit. High temperature, both air and soil, and vapour pressure deficit adversely influenced the button shedding in coconut in the absence of soil moisture. It is evident during the summer. The low button shedding from June to November could be attributed to less vapour pressure deficit in the crop environment under no soil moisture stress. The biotic factors like the incidence of pest and diseases may also involve in the case of button shedding. When considered all the biotic and abiotic factors, the seasonal variation in button shedding is predominantly influenced by soil moisture and vapor pressure deficit along with the number of female flowers.

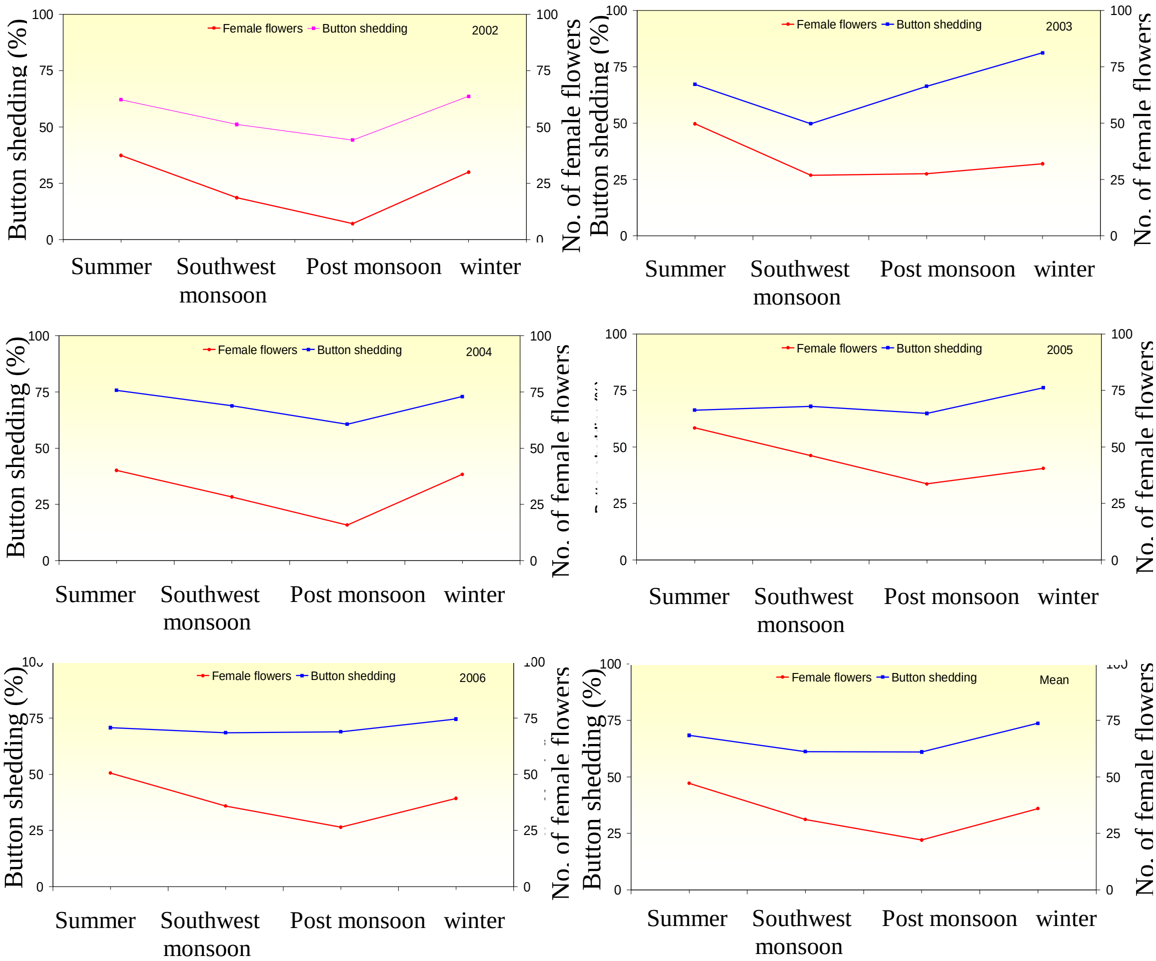


Fig. 4.27: Monthly female flower production versus button shedding in coconut

4.4.4.3 Estimation of button shedding in coconut

The principal component analysis of pooled data indicated that the maximum temperature alone accounts for 65.7% of variance and the minimum temperature accounts 19.4% of variance. The above two components together explained 89.1% of variance. Linear regression equation was developed based on the mean monthly maximum and minimum temperatures for estimation of monthly button shedding in coconut. The regression equation obtained is presented below:

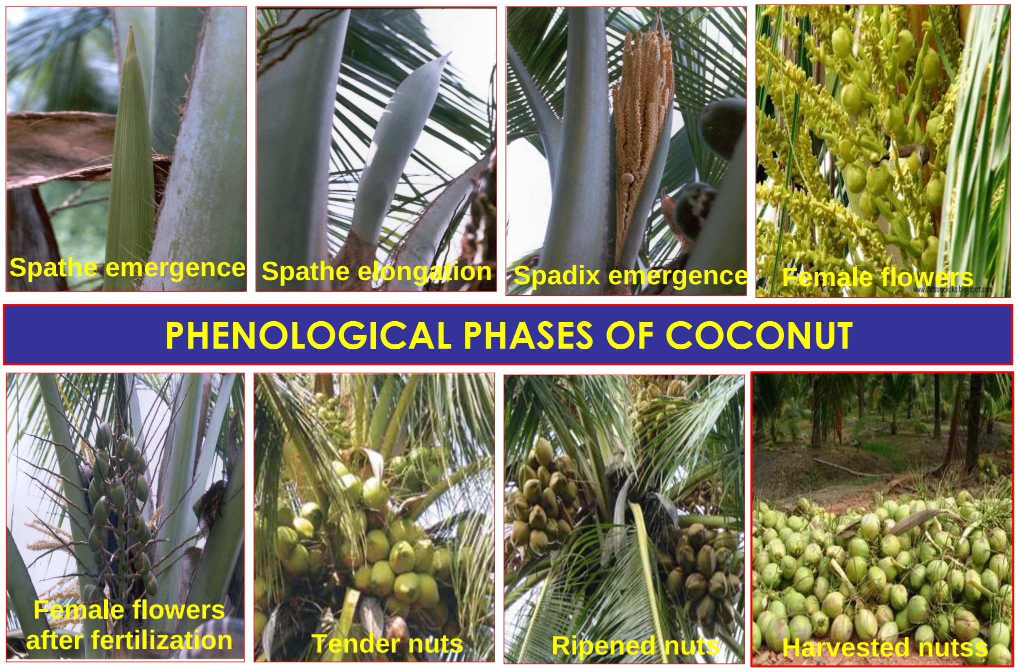
$$Y=1.681*X_1+3.658*X_2-73.042 \quad (F\ (1,272) = 18.345,\ P<0.001)$$

The equation is significant at 0.01% level. Where Y=Button shedding in percentage, X_1 = Maximum temperature (°C) and X_2 = Minimum temperature (°C)

4.5 COCONUT PRODUCTION

4.5.1 Development of nut

The female flowers that are not shed develop and become fully mature in the course of about 12 months. During the first two months of growth, the inner volume is provided with liquid endosperm. The endosperm surrounds a hollow interior space, filled with air and often a liquid referred to as coconut water. This liquid endosperm contains different saccharides, elements and enzymes.



These products later help the embryo during its germination and growth. During the third month of development the endocarp or the shell develops, and the colour less solid known as the endosperm appear as small platelets. The endosperm increase gradually in density and attains white in colour during the fifth month. The liquid endosperm becomes sweet and surface of shell is fully packed with thick white kernel. At 5 to 5.5 months of its development, the nut is considered to be the ideal for use as tender nuts. The kernel is fully formed by 8th month of growth. The oil content of the kernel also increases at this stage. Normally it takes about 10 to 12 months for the nut to mature. Patel (1938) reported that the growth period of spadix from initiation of primordium to ripening of nuts takes about 44 months. Critical stages of the development of the spadix have great influence on yield of nuts. The coconut palm produces one mature bunch more or less regularly in every month. Thus at any particular time, each palm has twelve (or more) bunches at different stages of development from which at least one mature bunch can be harvested monthly. The influence of weather is same on each bunch (or harvest) and there are marked differences in quality and quantity of nuts from successive harvest.

4.5.2 Varietal and seasonal effects

The annual coconut production was high (75.8/palm) in Tiptur Tall while low (61.5/palm) in Kuttiadi. It indicated that Tiptur Tall appears to be better among the four cultivars tested in terms of annual coconut production. On an average, the annual coconut production was 68.3/palm/month (Table 4.29). The mean monthly coconut production was maximum (9.9/palm/month) in April, followed by March (9.6/palm/month), May (8.9/palm/month) and June (7.3/palm/month) while it was minimum (2.1/palm/month) in December, followed by November (2.5/palm/month) and October (3/palm/month).

Table 4.29: Month-wise coconut production of different cultivars in coconut

Month	Cultivar				**Mean**
	Tiptur Tall	Kuttiadi	Komadan	Kasaragod	
January	4.0	3.7	4.0	4.1	**4.0**
February	7.5	6.3	7.3	6.6	**6.9**
March	10.8	9.1	9.4	9.3	**9.6**
April	10.8	9.1	9.9	9.8	**9.9**
May	10.0	7.9	9.0	8.6	**8.9**
June	8.2	6.3	7.8	6.9	**7.3**
July	7.1	5.1	6.4	5.8	**6.1**
August	5.0	4.2	4.5	4.5	**4.5**
September	3.9	3.4	3.6	3.2	**3.5**
October	3.4	2.6	3.3	2.8	**3.0**
November	2.7	2.2	2.8	2.3	**2.5**
December	2.5	1.7	2.3	1.9	**2.1**
Annual	**75.8**	**61.5**	**70.3**	**65.7**	**68.3**

The study revealed that the coconut production is high (9.5/palm/month) during summer while low (2.5/palm/month) during post monsoon season and intermediary in southwest monsoon (5.3/palm) and winter (4.3/palm). All the cultivars followed the same seasonal trend in coconut production (Table 4.30).

Table 4.30: Mean number of coconut in test cultivars during 2002 to 2007

Season	Tiptur Tall	Kuttiadi	Komadan	Kasaragod	**Mean**
Summer (Mar-May)	10.5	8.7	9.4	9.2	**9.5**
SWM (Jun.-Sept)	6.0	4.7	5.5	5.1	**5.3**
PM (Oct.-Nov)	3.1	2.4	3.0	2.6	**2.8**
Winter (Dec.-Feb.)	4.7	4.0	4.6	4.2	**4.3**
Mean	**6.1**	**5.0**	**5.6**	**5.3**	5.5

As a whole, the coconut production during summer (March - May) was high contributed 41.7% to annual coconut production, followed by southwest monsoon (31.3%) and winter (18.9%). The minimum (8.1%) contribution was during post monsoon season (Table 4.31).

Table 4.31: Percentage contribution of seasonal coconut production to annual

Season	Nut yield /palm	Percentage contribution to annual yield
Summer	28.5	41.7
Southwest monsoon	21.4	31.3
Post monsoon	5.5	8.1
Winter	12.9	18.9
Annual	68.3	100

4.5.3 Effects of weather

Year to year coconut production during the study period varied significantly, having maximum (79.5 nuts/year) during 2006, followed by 2004 (77.7 nuts/year) and 2002 (69.5 nuts/year) while minimum (51.7 nuts/year) during 2005 (Table 4.32) and 2003 (54.3 nuts/year).

Table 4.32: Mean monthly coconut production in different years

Month	2002	2003	2004	2005	2006	2007	**Mean**
January		2.8	4.1	3.1	5.0	5.3	**4.0**
February	6.6	5.5	8.4	4.9	8.0	8.3	**6.9**
March	10.1	7.4	10.8	8.1	11.0	10.5	**9.6**
April	10.6	8.6	10.9	8.0	11.0	10.6	**9.9**
May	9.8	7.2	9.9	7.0	10.2	9.2	**8.9**
June	8.2	5.0	7.9	4.9	8.9	8.4	**7.3**
July	7.2	4.5	7.0	4.4	7.4	-	**6.1**
August	5.0	3.9	5.6	3.2	5.1	-	**4.5**
September	3.8	3.0	4.2	2.6	4.2	-	**3.5**
October	3.0	2.6	3.6	2.2	3.6	-	**3.0**
November	2.8	2.1	3.0	1.9	2.9	-	**2.5**
December	2.3	1.7	2.5	1.5	2.5	-	**2.1**
Annual	**69.5**	**54.3**	**77.7**	**51.7**	**79.5**	**-**	**68.3**

The mean monthly nut production was also high (6.6 nuts/palm) during 2006, followed by 2004 (6.3 nuts/palm), 2002 and 2007 (6.1 each nuts/palm) while low (4.3nuts/palm) during 2005 (Fig.4.28) and 2003. It resulted on annual variation in coconut production.

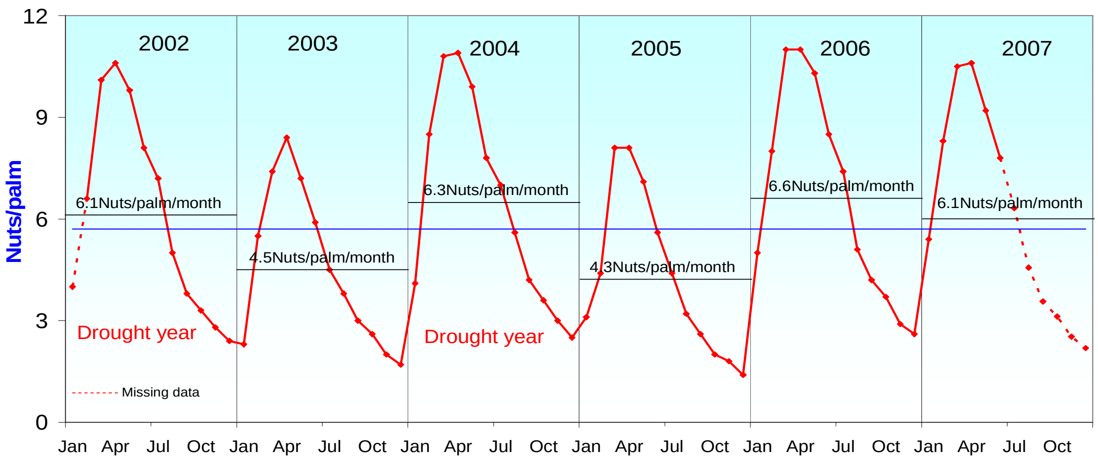


Fig. 4.28: The effect of drought on monthly coconut production (nuts/palm) at vellanikkara

The coconut production is comparatively low during 2003 and 2005. The low coconut production during 2003 and 2005 was mainly attributed due to the summer drought during 2002 and 2004. In both the years, there was a prolonged dry spell from late November to March (Figs. 4.29 and 4.30). The summer drought of 2004 was declared as one of the severe droughts during which several crops were adversely affected.

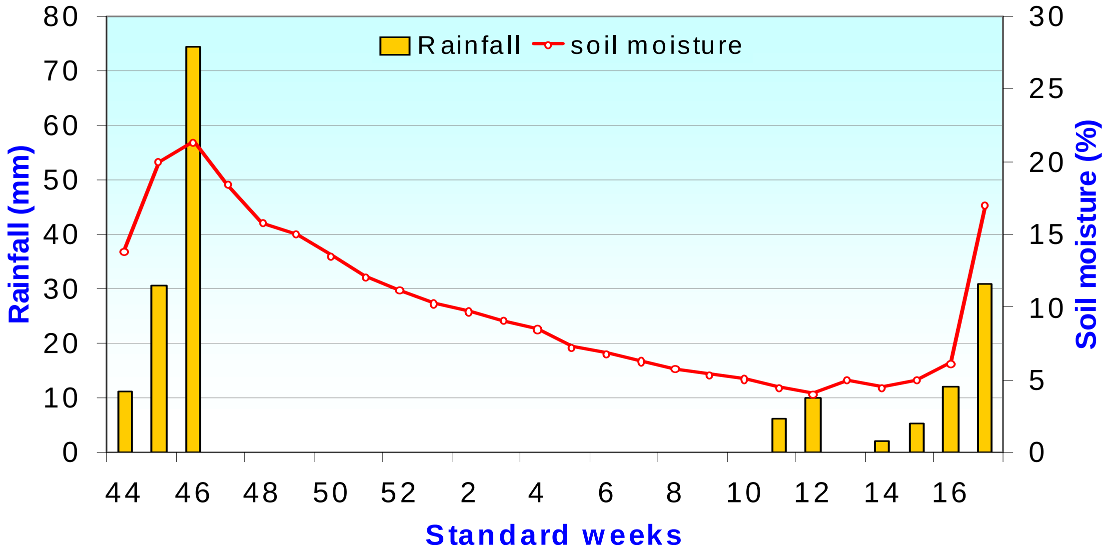


Fig. 4.29: Weekly soil moisture (%) at Vellanikkara from November, 2001(44th week) to April (17th week) 2002

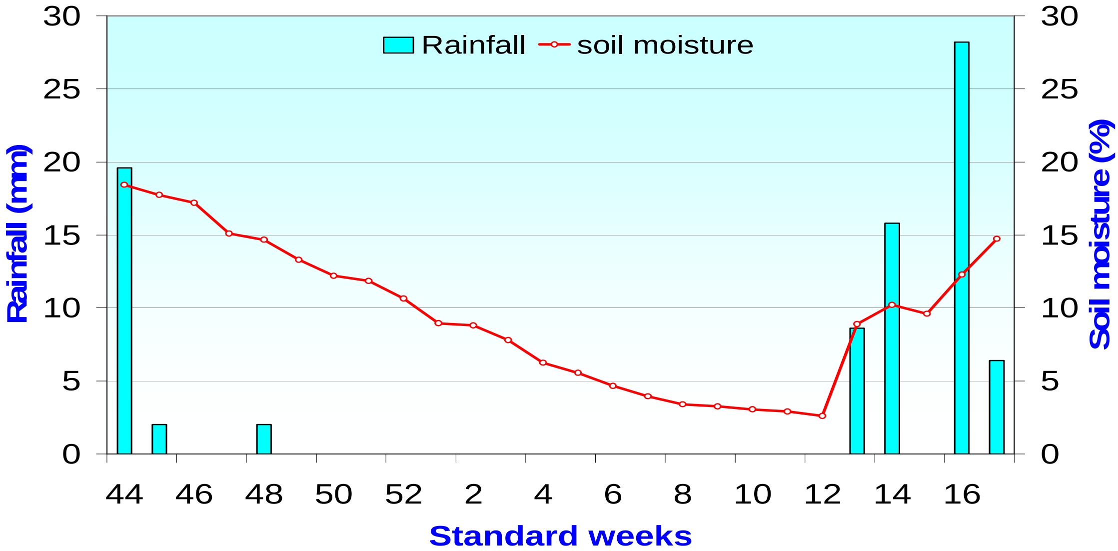


Fig. 4.30: Weekly rainfall versus soil moisture from November 2003 to April 2004 at Vellanikkara

It is interesting to note that the decline in nut production due to summer drought of 2002 and 2004 was noticed in 2003 and 2005 respectively. Decline in nut production was started in the 8th month (January) after the drought period was over and it continued upto December in both the years. Maximum decline in the monthly nut yield was noticed in the month of June 2003 and 2005 (Fig.4.31). It revealed that yield reduction was noticed in the following year from eighth month onwards and reached to its peak in the 13th month and decline in yield continued up to 18th month after the drought period was over.

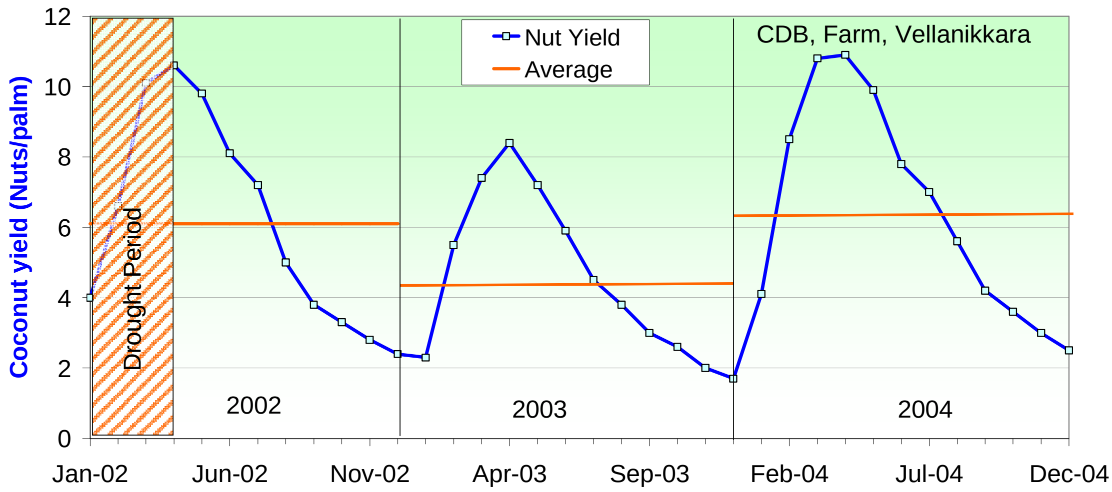


Fig.4.31: Effect of drought during summer 2002 on coconut yield at CDB Farm, Vellanikkara

As a whole, the coconut production was maximum (28.1 nuts/palm/year) during summer while minimum (5.5nuts/palm/year) in post monsoon during the study period (Table 4.33).

Table 4.33: Mean coconut production in different seasons

Season	Summer (Mar-May)	SWM (Jun.-Sept)	PM (Oct.-Nov)	Winter (Dec.-Feb.)	**Total**
2002-03	30.5	24.0	6.0	10.2	**70.7**
2003-04	23.0	17.3	4.6	14.3	**59.1**
2004-05	31.5	24.5	6.6	10.0	**72.6**
2005-06	23.2	15.8	3.8	14.4	**57.2**
2006-07	32.2	25.1	6.7	16.3	**80.2**
Mean	**28.1**	**21.3**	**5.5**	**13.0**	**67.9**

The result was in agreement with Rao (1988) and Rao, *et al*., (1993). The decline in yield was 20.6% during 2003 while 24.4 % during 2005 against normal. The increase in coconut yield was 1.7% and 13.7% during 2002 and 2004, respectively (Table 4.34).

Table 4.34: Percentage deviation of coconut production from the mean in different seasons

Season	Summer (Mar-May)	SWM (Jun.-Sept)	PM (Oct.-Nov)	Winter (Dec.-Feb.)	**Total**
2002-03	8.5	12.6	9.3	-21.7	**4.1**
2003-04	-18.2	-19.1	-17.0	9.8	**-13.0**
2004-05	12.3	15.0	18.9	-23.6	**6.8**
2005-06	-17.2	-26.0	-31.9	10.6	**-15.9**
2006-07	14.6	17.6	20.7	24.8	**18.0**

Interestingly, an increase of 16.3% was noticed in coconut yield during 2006. It was mainly attributed to the intermittent rainfall received up to the second week of November and an amount of 7.6 mm rainfall was received in January (30.1.2005). April month alone received very good amount of showers (260.6 mm). The soil moisture content was relatively high (11.5%) during this period (Fig.4.32). That is why the coconut production was more by 16.3% in 2006. As far as coconut production is concerned, the year 2006 was a good year during the study period (2002-2007). This was not the case in 2004 summer, early withdrawal of northeast monsoon in 2003, followed by long dry spell extended up to last week of March resulted to severe soil moisture stress (*see Fig 4.30*). In addition to this, day maximum surface air temperature reached up to 39.4°C (2nd, 15th and 16th March 2004) which was the highest temperature noticed during the last one decade.

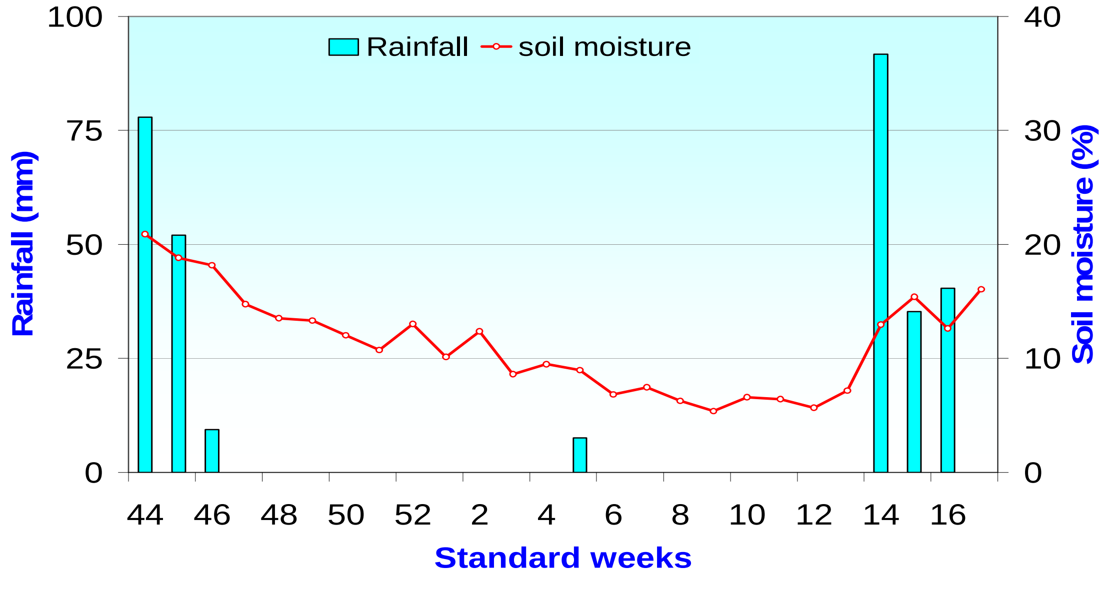


Fig. 4.32: Weekly rainfall versus soil moisture from November 2004 to April 2005 at Vellanikkara

The summer 2002 also followed the same trend as long dry spell after second week of November 2001 to third week of March 2002 led to drought condition during summer 2002. The maximum surface air temperature reached up to 38.8°C (12.3.02) during summer 2002 (Fig. 4.33).

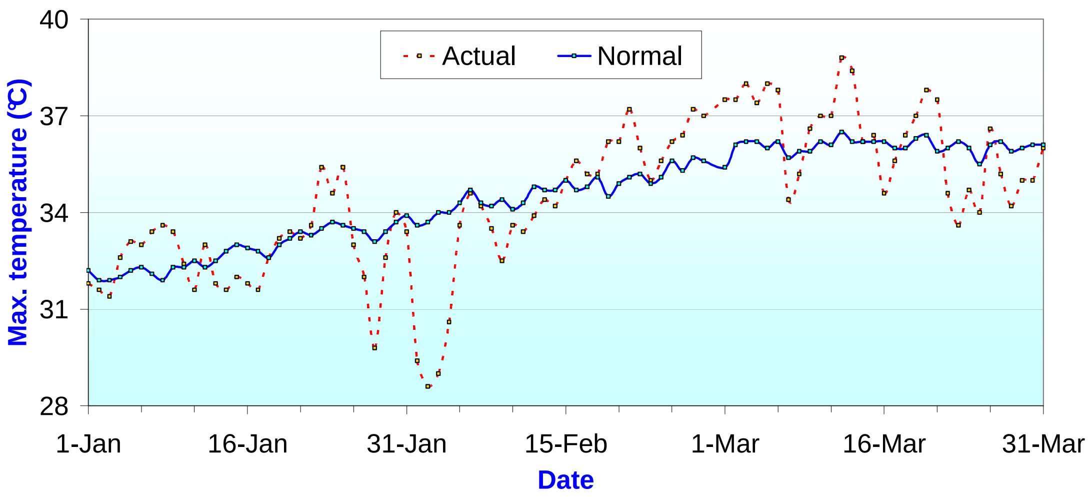


Fig. 4.33: Daily maximum surface air temperature against normal from 1st January to 31st March, 2002

This situation led to low coconut production in the following years 2003 and 2005 due to summer drought in 2002 and 2004. It revealed that early withdrawal of northeast monsoon and late commencement of summer showers led to severe moisture stress during summer 2002 and 2004. During the above years, the daily maximum air temperature shot up to 38 to 39°C during summer months. This situation led to summer drought conditions in the Central Zone of Kerala. The annul coconut production declined up to 20.6 - 24.4 % of normal value during 2003 and 2005, respectively. The study revealed that though the annual coconut production depends up on the weather factors three - and - a - half - years ahead, the decline in coconut production due to severe summer drought could be seen in the following year. Similarly good summer showers with less duration of dry spell are likely to influence the coconut yield favourably in the following year. This could be explained due to the sensitiveness of various critical crop growth stages to soil moisture stress, which finally decides the nut yield in coconut.

4.5.3.1 Effect of dry spells on the initiation and development of inflorescence and coconut yield

Development from the flower primordium to harvest stages of mature nuts take 44 months of which 12 months represent the period taken from the opening of spathe to harvest. Effect of weather is evident at all the stages of development but the influence of weather depends on the stages of nut development. Coconut is mainly grown under rainfed conditions in areas of high rainfall. However, these plantations face summer drought situations as the rainfall distribution is restricted to only 4 to 5 months a year, leaving remaining period as dry. In view of the long duration (44 months) between the inflorescence initiation and nut maturation, the occurrence of dry spell in any year would affect the yield for the subsequent three to four years. Rainfall, temperature of both soil and air, vapour pressure and wind speed are the major weather variables that influence the yield when other external factors such as female flower fertilization and crop management practices are not limiting. Park (1934) observed that the severe drought experienced in Sri Lanka affected nut yield for about two years, with maximum effect occurring about 13 months after the end of the drought. This was confirmed by Rao (1986) who showed that the effect of drought on nut yield was commenced with eighth month and continued for a period of twelve months thereafter, with a maximum nut reduction in the 12/13th month after the drought period is over. Rajagopal *et al.*, 1996 observed that the nut production under rainfed condition is influenced significantly by the length of dry spells at critical stages and the dry spell during the primordium, ovary development and button size is crucial for the production of nut yield. He also reported that nut production can be sustained at relatively high by giving life saving irrigation during the summer months. Kumar *et al.*, 2007 reported that longer dry spell affects the nut yield for next four years to follow with stronger impact on fourth year, irrespective of the total rainfall. Since coconut has long reproductive phase, it is difficult to assess the critical stages which are affected due to soil moisture stress under field conditions. Thus, there is lack of literature on interaction between the occurrence of dry spell and its effects on various development stages in coconut. Therefore, a systematic attempt has been made to assess the impact of dry spell on initiation and development of inflorescence and nut yield. The results of which are summarized below:

The schematic representation of the influence of dry spells on the origin and development of inflorescence is illustrated in Fig. 4.34 (A to F).

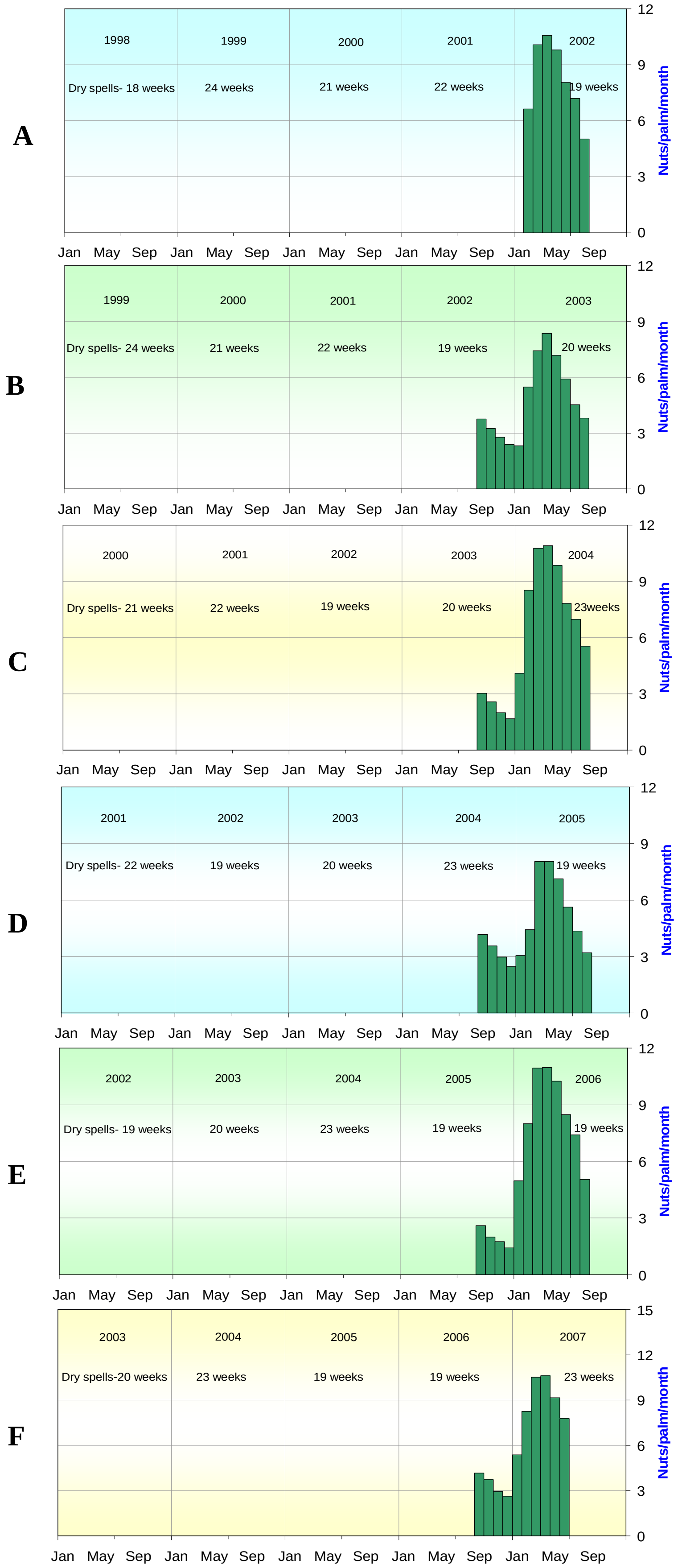


Fig. 4.34: Duration of dry spells and monthly coconut yield at CDB Farm, Vellanikkara

It is evident that the inflorescence primordium which was initiated in the month of June 1998 attained maturity by February 2002 and the one initiated in July 1998 matured by March 2002 and so on (primordium initiation ending with December, 1998 matured in August 2002 to complete the one life cycle of coconut production). Like wise, the Figures B to F represent the data for the next set of four years 1999 to 2002-03, 2000 to 2003-04, 2001 to 2004-05, 2002 to 2005-06, 2003 to 2006-07, respectively. In all the above years, the monthly nut yield of coconut was low (histograms on the right scale) from September to January. It could be traced back to the initiation of respective primordium during the dry months three years earlier (January-May). On the other hand, high nut yields obtained from February to July could be attributed to the primordium initiation coinciding with rainy months between June and November three years earlier. From the above, it is clear that length of dry spell during summer prior to the previous three years influenced the nut yield pattern and the dry spell during the current year of harvest had no influence on nut yield. It is very clear from the yield data of 2003-04 (Fig. 4.34 C) which had 23 weeks of dry spells but still produced high yield. Inflorescence primordium of these bunches was initiated during 2000, experiencing 21 weeks dry spells, followed by a wet spell (1672.4 mm) during the monsoon months of 2000. This is very well reflected in the low yield (3.3 nuts/palm) from September 2003 to January 2004, and very high yield (11.5 nuts/palm) from February to July (2003-04) corresponding to the rainiest months of June - November 2000. This is mainly due to recovery of palms immediately preceded by prolonged moisture stress, which might have facilitated the mobilization of reserve food material (Stored stress) to the developing sinks (Rajagopal *et al*., 1996). It is very clear that nuts/palm in any month is not influenced by the weather factors during that month. This is proved by the fact that even though a dry spell existed from February to May, the nut yield during these months always remained high irrespective of the good and poor coconut yield year. Poor nut yield from September to January, in spite of relatively very low dry spells, is indicative of the bunches with few nuts due to prolonged dry spell noticed during various critical stages of primordium initiation to nut development.

In order to find out the critical stages that are influenced due to prolonged dry spell during the coconut development, the primordium initiation period has been grouped into three categories viz., the primordium initiation from January to May (group A), June to September (group B) and October to December (group C). Total dry spell during the various development stages of nut development varied between 33 to 71 weeks during the study period. The group A is characterized by maximum dry spells at almost all stages of nut development (71 weeks dry spell from January 1998 to September 2001). As a whole, the primordium initiated from January to May accounts for 34.4% of total reproductive stage was expose to dry spell while 24.7 % in the case of group B and group C (19.4%). Group B had a total dry spell of only 1 to 4 weeks during primordium initiation stage and ovary development stage. Total dry spell ranges from 41 to 50 weeks during the study period in the case of Group B. Group C has a total dry spell of 33 to 39 weeks and majority of growth stages did not experience dry spell (Table 4.35). The mean monthly nut yield per palm of group A ranged from 2.6 to 3.8 indicating that the total mean dry spell of 64.8 weeks with 20.1% occurring at primordial stage is highly detrimental for nut production. Conversely, 46.5 weeks (Group B) is less damaging especially because of less dry spells of 1, 4 and 6 critical stages (Primordium initiation, Ovary development and mature nut stage) and it was relatively free from drought. This is very well supported by yield data which recorded a monthly average of 8.8 nuts per palm. The average nut production was 6.2 nuts per palm in Group C palms in which the dry spell was intermediary. The primordium initiation in group C commences under relatively low dry spell between October and December and it experience dry spell from January to May. That is the reason why the nut yield was relatively better when compared to group A in which primordium was initiated from January to May.

Table 4.35: Dry spells during different stages of nut development

Year	Group	Months of Initiation	Total period of dry spells at various stages							Total	Mean yield (nut /month)
			1	2	3	4	5	6	7		
1998	A	Jan-May	14	4	10	14	8	11	10	71	-
	B	Jun-Sep	0	11	13	1	11	10	1	47	9.3
	C	Oct-Dec	4	11	1	6	1	0	10	33	6.8
1999	A	Jan-May	13	3	7	14	7	12	8	64	2.9
	B	Jun-Sep	4	10	13	1	8	8	2	46	7.1
	C	Oct-Dec	7	12	1	7	3	0	9	39	4.7
2000	A	Jan-May	14	2	8	12	9	11	7	63	2.7
	B	Jun-Sep	1	11	11	2	13	7	1	46	10.0
	C	Oct-Dec	6	10	1	5	1	0	12	35	6.8
2001	A	Jan-May	14	2	7	11	9	13	10	66	3.3
	B	Jun-Sep	1	9	8	1	11	10	1	41	6.9
	C	Oct-Dec	7	7	3	8	1	0	12	38	4.4
2002	A	Jan-May	12	4	9	14	7	13	8	67	2.6
	B	Jun-Sep	2	12	13	1	11	8	2	49	10.0
	C	Oct-Dec	5	12	1	8	1	2	9	38	7.0
2003	A	Jan-May	11	2	9	12	7	9	8	58	3.8
	B	Jun-Sep	1	12	11	2	14	8	2	50	9.6
	C	Oct-Dec	8	10	1	5	1	2	9	36	-
Mean	A	Jan-May	13.0	2.8	8.3	12.8	7.8	11.5	8.5	64.8	3.1
	B	Jun-Sep	1.5	10.8	11.5	1.3	11.3	8.5	1.5	46.5	8.8
	C	Oct-Dec	6.2	10.3	1.3	6.5	1.3	0.7	10.2	36.5	5.9

It clearly revealed that the dry spell during the first phase (primordium initiation) is very critical. In addition, the seven stages of nut development may not exactly pass through drought in this group C, which resulted in better nut yield. When we compare the primordium initiation stages of different groups, it is clear that primordium initiation during the dry period immediately followed by recovery period (during monsoon) and entering moisture stress immediately after a brief period of normal soil moisture availability. In the group A palms, even if there was initial stress to palms, there is possibility of revival these stresses during monsoon extending four months where in group C palms even though the palm started with initial advantage of adequate moisture availability, the subsequent dry spell of 11 to 14 weeks could damage, if not completely inhibit their development. Group A exhibited a more favourable period (monsoon) after initiation of primordium than group C. Thus, the table clearly reveals that Group B conditions are most favourable for maximum nut production. From the above, it is clear that the total rainfall, number of rainy days and the total dry spell are not as crucial as the length of dry spell at the critical stages such as primordium initiation, ovary development and button size nuts which ultimately determine the yield potential of rainfed coconut palms. As the 5 year average dry spell for the study period (Group A) revealed that out of 64.8 dry weeks, primordium initiation, ovary development and button size nut stage experienced 13.0, 12.8, 11.5 dry weeks, respectively. These three stages altogether accounted for 57.5% of total dry spell while other stages remained 42.5%. This result confirms with the study of Rajagopal *et al.,* (1996). It accounts for total duration of dry weeks as 20.1%, 19.7%, and 17.7% only during primordium, ovary development and button size nut stage, respectively. It revealed that primordium stage was most sensitive to moisture stress, followed by ovary development stage and the stage of button in coconut.

The monthly rainfall pattern, interspersed with dry spell between January 2002 and December 2006 is illustrated in the lower part of Fig. 4.35 to understand the effect of dry spell on number of growth stages of coconut and its overlapping. The number of growth stages is divided into seven critical stages viz., primordium initiation stage (1), branch development of inflorescence (2), male and female flower development stage (3), ovary development stage (4) and spathe opening stage (5), button size nut (6) and mature nuts (7) stage. They are closely related to the development of inflorescence during which distances or overlaps between the seven stages among the three groups were noticed. It was more so in the first two groups. It is noted that the length of dry spell at each stage was the highest in group A, followed by group B and group C. The nut yield per palm from September 2005 to August 2006 with three distinct trends is a direct reflection of the initiation of primordium and its development as coconut were subjected to the influence of rainfall or dry spells.

It revealed that the monthly nut yield is better if the critical developmental stages of coconut experience less number of dry spells and vice-versa. That is the reason why, the monthly nut yield is better from January to May, followed by June to September. It is the least from October to December.

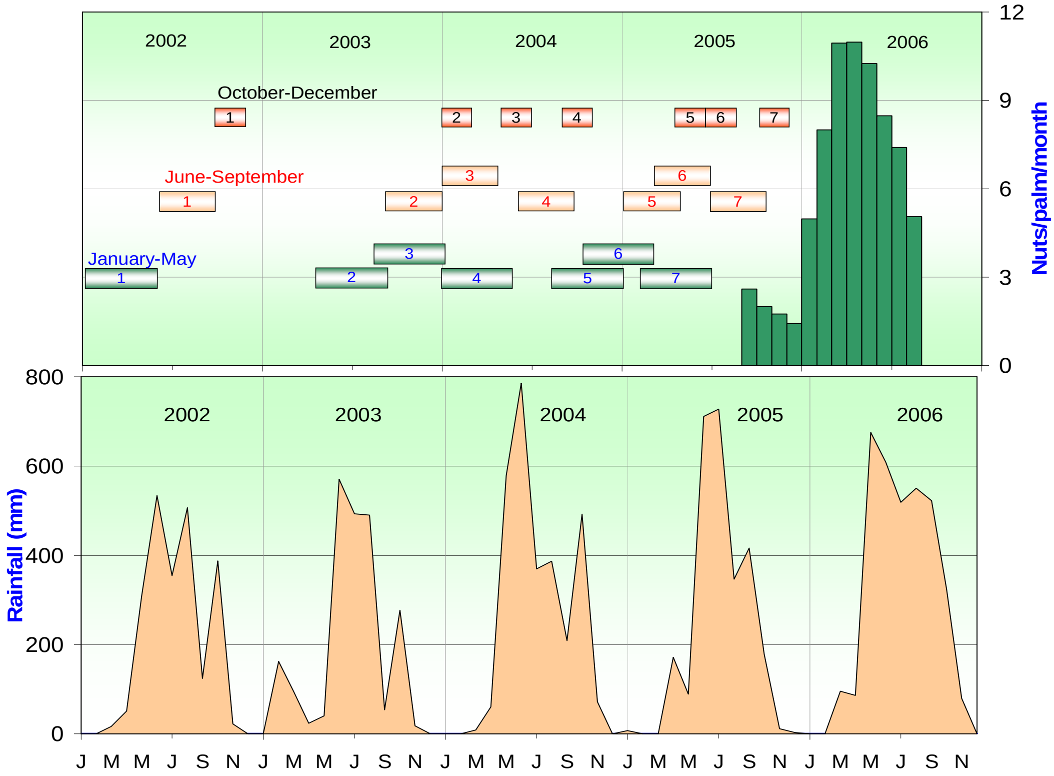


Fig.4.35: Schematic diagram of monthly rainfall (peaks) or dry spells (trough) superimposed on growth stages of inflorescence in coconut

The correlation studies indicated that rainfall had positive influence on four of seven lag periods [primordium initiation stage (44 months prior to the harvest),ovary development stage (19-20 months prior to harvest), button size nut stage (8-9 months prior to harvest) and mature size nut stage (6-8 months prior to harvest)] while temperature and vapour pressure deficit had positive influence on three lag periods [branch development stage (29 months prior to harvest), male and female development stage (24-25 months prior to harvest) and spadix emergence (12 months prior to harvest)]. It indicates that if monsoon failed and dry weather continued during the critical stages mentioned above, the yield would be drastically reduced. Fluctuations in coconut yield during different years could be thus explained on the basis of variations in rainfall pattern. At Vellanikkara, early cessation of the Northeast monsoon during 2001 followed by late commencement of summer showers during 2002 led to prolonged dry spell of 19 weeks from November 2001 to May 2002. Similar was the case in 2003-04 also with a dry spell of 22 weeks from November, 2003 to April 2004. Rajagopal *et al.*, (1996) reported that the unprecedented drought adversely affected coconut palms in different degrees, such as the total absence of inflorescence in some leaf axils, the emergence of inflorescence bunches without flower initials, enhanced shedding of female flowers and immature nut fall, depending on the stages of growth which suffered due to the effect of dry spell the most. That might be the reason for low coconut production in 2003 and 2005. Nelliat and Padmaja, 1978 showed that coconut palm respond well to summer irrigation (January to May). This clearly indicates that adequate soil moisture during primordium initiation is most essential. This is in agreement with the present study that enough soil moisture availability through adequate rainfall (Group B) increased nut production, while inadequate soil moisture in summer months (Group A) adversely affected nut production. The above study revealed that coconut production under rainfed conditions is influenced significantly by the length of dry spell at critical stages. The availability of adequate soil moisture during the primordium initiation stage, ovary development stage and button size nut stages are the most crucial for final harvest of coconuts. It is probably known, why, coconut production under irrigated conditions is much better when compared to that of rainfed conditions. The effect of dry spells on several behaviour of morphological and biotic events could be well understood provided these studies are taken up under well irrigated coconut gardens.

4.5.4 Forecasting of Monthly yields

To study the association between the weather variables and nut yield of coconut, correlations were worked out in seven critical stages viz., primordium initiation, branch development stage of inflorescence, male and female flower development stage, ovary development stage, spadix emergence stage, button nut size and mature nut stage as these biotic phases are vital for final yield of coconut. These above phases coincide with 44 months, 29 months, 24-25 months, 19-20 months, 12 months, 9 months and 6-8 months, respectively prior to the harvest.

The correlations between the monthly coconut production and weather parameters during primordium initiation stage (44 months prior to the harvest) indicated that temperature both air and soil, vapour pressure deficit, sunshine and evaporation had significant(0.01 level) negative correlation while rainfall, soil moisture and number of rainy days had significant(0.01 level) positive correlation with monthly nut yield. It revealed that the coconut production is influenced by abiotic factors during various critical stages. High temperature, both air and soil, vapour pressure deficit and low rainfall with less number of rainy days 44 months ahead and 19-20 month ahead adversely affected the monthly nut yield in coconut. The above weather variables during the male and female development stages influenced positively the coconut yield.

The influence of weather parameters during the spadix emergence (12 months prior to harvest) on the monthly nut yield indicated that the temperature of both air and soil, vapour pressure deficit, wind speed, sunshine hours and evaporation also had significant (0.01 level) positive correlation with nut yield and soil moisture, rainfall and rainy days had significant (0.01 level) negative correlation with yield. But during the button size nut stage (9 months prior to harvest), rainfall, minimum temperature, soil moisture and number of rainy days had significant positive correlation with nut yield while soil moisture, rainfall and rainy day had significant negative correlation with yield. During the later stages (mature nut size), rainfall, soil moisture and number of rainy days had significant (0.01 level) positive correlation with nut yield while temperature of air and soil, vapour pressure deficit, wind speed, sunshine and evaporation had significant (0.01 level) negative correlation with yield .

The pooled weather data during the primordium initiation (44 months prior to harvest), development of branches of inflorescence stage (29 months prior to harvest), male and female flower stage (24-25 months prior to harvest), ovary development stage, spadix emergence (19-20 months prior to harvest), button size nut (9 months prior to harvest) and mature nut size (6-8 months prior to harvest) stage was subjected to principal component analysis. It indicated that mean vapour pressure deficit during the ovary development stage alone accounts for 41.9% of variance while maximum temperature during the button size nut stage 28.6%, minimum temperature during the spadix emergence stage 10.1%, minimum temperature during branch development stage of inflorescence 4.1%, wind speed at the spadix emergence stage for 2.6%, evaporation during the button size stage accounts 1.6% and evaporation during the ovary development stage 1.1% of variance. Thus, these seven weather variables together explain 90% of variance. The linear regression equation developed based on these monthly weather variables at various critical stages and monthly nut yield as follows.

$$Y= 53.093 - 0.402*X_1 - 0.009*X_2 + 0.092*X_3 - 0.783*X_4 + 0.183*X_5 - 0.803*X_6 - 0.010* X_7 \ (R^2 = 0.78)$$

Where Y= monthly coconut yield, X_1 = Mean vapour pressure deficit during the ovary development stage, X_2 = Evaporation during the ovary development stage, X_3 = Minimum temperature during the branch development of inflorescence, X_4= Minimum temperature during the spadix emergence, X_5 = Wind speed during the spadix emergence stage, X_6 = Maximum temperature during the button size nut stage and X_7 = Evaporation during the button size nut stage. The equation is significant at 0.01% level ($F(7, 64) = 29.574$, $P<0.001$).

Actual and estimated monthly nut yield per palm using the above equations is illustrated in Fig.36. The results indicated that the actual and estimated values were in good agreement. It can be used for forecasting monthly coconut yield at farm level. If it is extended for Thrissur district, the district level coconut yield can be predicted Month - wise. Probably, this is the first attempt in coconut on monthly nut yield prediction based on weather variables.

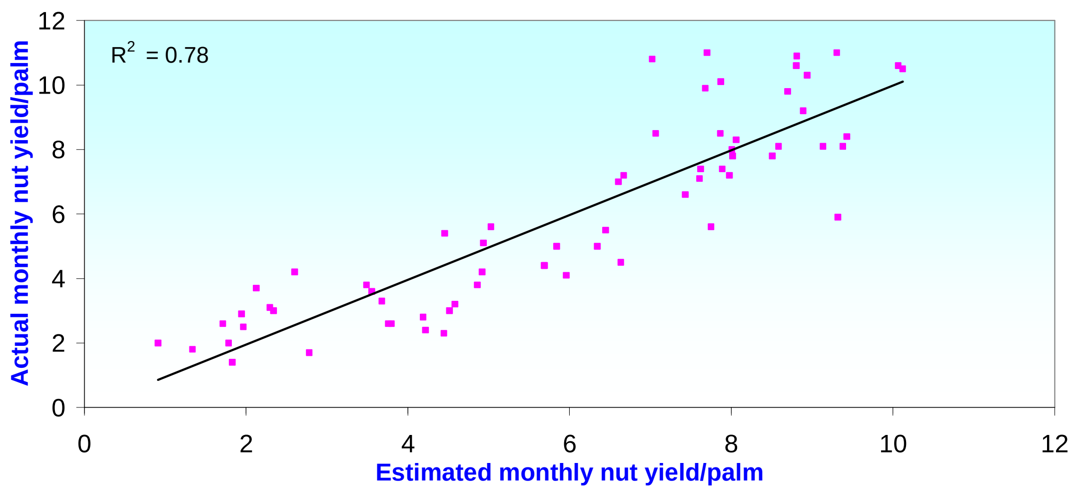


Fig.36: Actual versus estimated monthly coconut yield (Nuts/palm) at CDB Farm, Vellanikkara from 2002 to 2007

Chapter V

Summer droughts and coconut production

5.1 INTRODUCTION

Drought is a natural hazard that has significant impact on economic, agricultural, environmental, and social aspects. It differs from other natural hazards by its slow accumulating process and its indefinite commencement and termination. Being a slow process although drought often fails to draw the attention of the farming community, its impact persists even after ending of the event. The reasons for the occurrence of droughts are complex, because they are dependent not only on the atmosphere but also on the hydrologic processes which feed moisture to the atmosphere. Once dry hydrologic conditions are established the positive feedback mechanism of droughts sets in, where the moisture depletion from upper soil layers decreases evapotranspiration rates, which, in turn, lessen the atmospheric relative humidity. The lesser the relative humidity the less probable the rainfall becomes, as it will be harder to reach saturation conditions for a regular low pressure system over the region. Drought is commonly considered to be a deficiency of moisture when compared to some normal or expected amount over an extended period of time. It is a normal, recurrent feature of climate and is observed in all the climatic zones. However, it has significantly different characteristics from one region to another. Drought differs from aridity. Aridity is a permanent feature of climate over regions where rainfall received is generally low. On the other hand, drought over a geographic area is a temporary condition caused by significantly less (deficient) rainfall for an extended period of time, usually during a season when substantial rainfall is normally expected over the area. Drought is a relative term used universally with reference to deficiency of rainfall when compared to normal rainfall of a given location.

It is a short- coming in understanding the drought as a period or periods of dryness is related to lack of rain and exists only when rainfall alone is less than normal. To overcome this, many attempts were made to define drought based on rainfall and temperature or rainfall and water need or consumptive use. Drought has multiple impacts on global agricultural, hydrological, eco-environmental and social-economical systems. Unusual periods of rain-free weeks can bring soil water deficits, result in high livestock mortality rates and disrupt reproduction cycles, and thus increase the likelihood of food shortages leading to malnutrition and hunger. A single definition of drought applicable to all spheres is difficult to formulate since concept, observational parameters and measurement procedures are different for experts of different fields. Besides, the concept of drought varies among regions of differing climates (Dracup *et al.*, 1980). Hence, there is a need to review the definition of drought across the different regions.

5.2 TYPES OF DROUGHTS

Drought can be classified as meteorological, hydrological, agricultural, socioeconomic and physiological depending upon the deficiency of rainfall or soil moisture stress. However, physiological drought can also occur due to waterlogging during monsoon in the humid tropics, where rainfall is very high. In general, the occurrence of drought is noticed in major parts of India during *kharif* when monsoon is delayed or it fails since crops are grown during the above period under rainfed conditions. The *kharif* crops raised during monsoon period may experience soil moisture stress depending on the number of rainless days associated with break of monsoon. The success of crops during the first crop season depends on monsoon behaviour. The India Meteorological Department defined drought based on rainfall and the area affected due to drought during the monsoon season. If the rainfall over the country is less by 10 per cent of the long period average and 20 per cent of the cropped area is affected due to drought, it is defined as the all-India drought.

Indian economy is mostly agrarian based and depends on onset of monsoon and its further behaviour. The year 2002 was a classical example to know how Indian kharif foodgrains production is dependant 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 the area was affected due to drought. Despite technological advantage to mitigate the ill effects of drought, the *kharif* foodgrain production was adversely affected; fell by a whopping 19.1%. At large, such adverse affect was not seen over Kerala on seasonal as well as plantation crops though the deficiency of monsoon rainfall was the highest (35% less to long period average). Though the monsoon rainfall was deficit, the rainfall distribution was such that the plantation crop production was not adversely affected. At the same time, it was the summer drought which affects plantation crops production in the humid tropics like Kerala as witnessed in 1983. Consecutive deficiency of monsoon rainfall since the last four years over Kerala may also have long standing ill effects on major plantation crops and seasonal crops that are grown during Mundakan and Puncha seasons due to shortage of water during summer. In contrast, several districts in Kerala experienced floods during October 2002, which led to floods and devastated plantations in Kannur and Kasaragod Districts. Kannur received 370 mm of rainfall on 14th October 2002, which was the highest and not received since 1924. All these reveal that weather related disasters viz. droughts, floods, landslides and thunderstorms are of great concern, leading to economic loss to a considerable extent in Kerala. Most of the plantation crops suffer due to soil moisture stress during summer. The classification of severity of drought in relation to coconut is very important. In the case of coconut, the nut yield is adversely affected in the following year up to 30 to 50 per cent depending upon the variety and crop management due to severe soil moisture stress during summer. The length of dry spells in relation to coconut yield is very important for assessing the nut yield. Keeping the above in view, the study was taken up to study the impact of summer drought on coconut yield based on the aridity index which is relatively a better drought index.

5.3 SUMMER DROUGHTS OVER KERALA

The State of Kerala experienced 29 summer drought years out of 58 (1951-2008), of which thirteen moderate, six large, nine severe and one disastrous drought (Summer 1983). The decade 1981-1990 experienced more number of droughts (7), followed by 1991-00 (6) and five in 1961-70. The number of drought years was minimum (3) during the decade 1971-80 (Table 5.1), followed by 1951-60 (4) and 2001-08 (4 each). Interestingly, the intensity of drought and number of drought years were more during the decade 1981-90 (7), during which the warmest year was also recorded in 1987 in Kerala.

Table 5.1: Occurrence and intensity of summer droughts over Kerala from 1951 to 2008

Decade	Intensity and occurrence of droughts					
	Moderate	Large	Severe	Disastrous	Total	%
1951-60	3		1		4	40
1961-70	4	1			5	50
1971-80	1	2			3	30
1981-90	1		5	1	7	70
1991-00	1	3	2		6	60
2001-08	3		1		4	50
Total	13	6	9	1	29	
Drought Intensity (%)	44.8	20.8	31.0	3.4		

The departure of aridity index from the median from 1951 to 2008 showed that it is shifted more towards drier side in recent decades especially form 1980 onwards (Fig. 5.1)

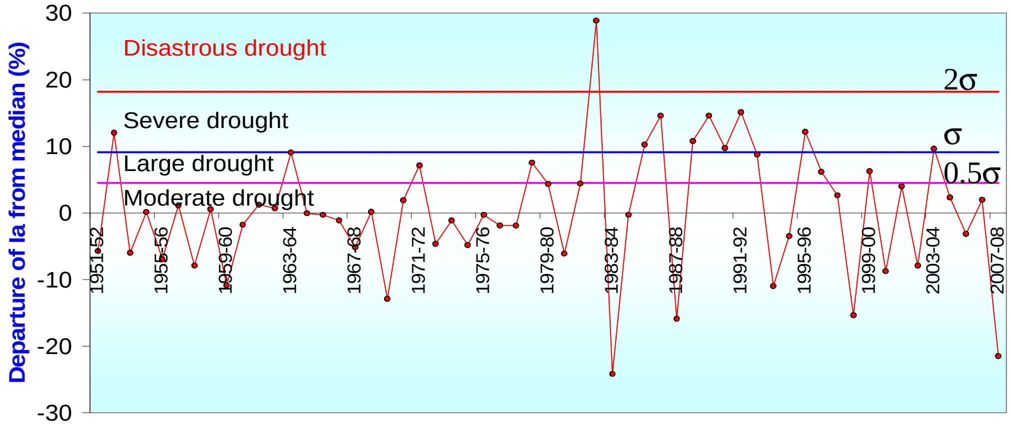


Fig. 5.1: Departure of Aridity index from the median from 1951 to 2008

The percentage occurrence of moderate drought was more (44.8%) across the State, followed by the category of severe (31.0%) and large (20.8%). Only one year fell (3.4 percent only) under the category of disastrous drought. The intensity and occurrence of severe and disastrous droughts were more in recent decades since 1981 onwards. The variation in aridity index over Kerala showed a marginal increase (3.2%) since last sixty years. It appears that the intensity of summer drought was more in recent decades, especially 1981-90, as the aridity was high. The decadal average of aridity index was high (56.4%) during 1981-90, followed by 1991-00(52.4%), 1971-80 (50.9 %) and 50.5% in 1961-70 while the aridity index was minimum (48.6%) during 1951-60 (Fig. 5.2).

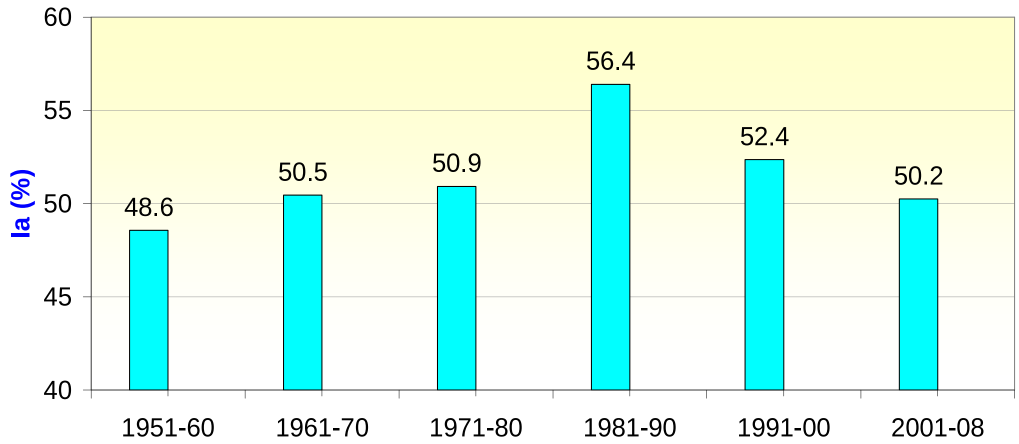


Fig. 5.2: Decade-wise aridity index from 1951 to 2008 over Kerala

Since the decade 1981-90 experienced the highest average aridity index, the more number of droughts were also noticed during that period. The three decadal mean of the aridity index showed an increasing trend. Five percent of increase in aridity index was noticed during 1981-2008 when compared to 1951-80 (Fig. 5.3) leading to more number of droughts in recent decades.

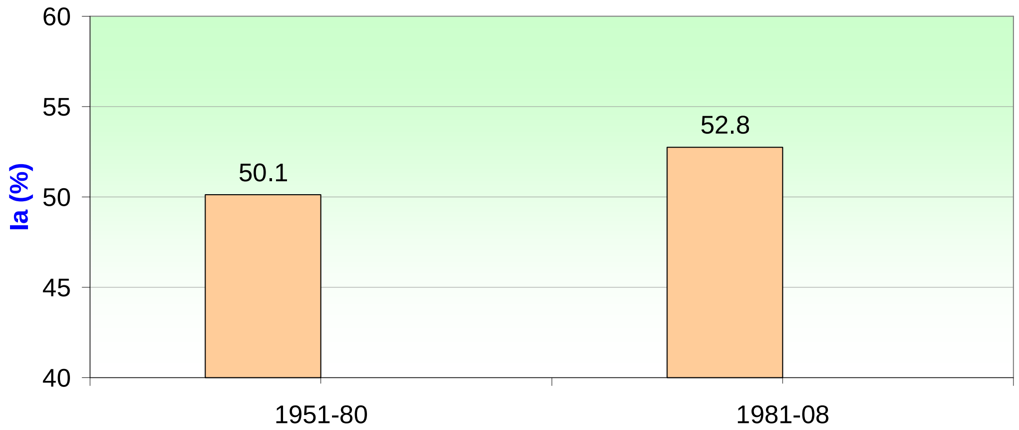


Fig. 5.3: Tri-decadal aridity index from 1951 to 2008 over Kerala

5.3.1 Drought characteristics in coconut

Coconut palms show the following characteristics under severe soil moisture stress depending upon the duration and intensity of summer drought as per the Rao *et al*., 2005.

- ❖ Withering and mortality in the case of young seedlings under poor management.
- ❖ Drooping, wilting and drying of lower whorl of leaves.
- ❖ Breakages of leaves at petiole or just above it.
- ❖ Spindle leaf breaking which lead to mortality in the case of 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 the subsequent year up to fifty per cent depending upon the type of management. Rethinam *et al*., 1987 reported that drought effects of adult palm characterized by bending of leaves, wilting in lower whorls, reduction in female flowers, shedding of buttons, immature nut fall and drastic decline in nut production.

5.3.2 Impact of droughts on coconut production over Kerala

Most of the plantation crops suffer due to soil moisture stress during summer**.** The seasonal and annual variations in coconut production is mainly attributed due to dry spells within the monsoon and soil moisture deficiency from December to May, if pre - monsoon showers fail, which is not uncommon in the humid tropics under rainfed conditions. The severity of soil moisture deficiency is more towards northern districts of Kerala due to uni- model high rainfall, followed by prolonged dry spell for four to six months. Of course, the soil moisture status depends not only on soil type but also on topography, which is a significant feature in Kerala as coconut cultivation is seen in low land, mid land and high lands. The State of Kerala experienced one disastrous drought (1982- 1983) since 1951. The decline in coconut production of Kerala was maximum during 1983-84 (18.3%) when compared to the previous year. The percentage decline in coconut production due to summer drought was 8.9%, 5.6%, 6.3%, 2.8%, 1.2% and 7.1% during 1952-53 (Severe), 1971-72 (Severe), 1978-79 (Moderate), 1989-90 (Severe), 1995-96 (Severe) and 2002-03 (Moderate) was respectively (Fig.5.4). Majority of drought years showed decline in yield in the following year. The average decline in coconut production in the following year was up to 18%.

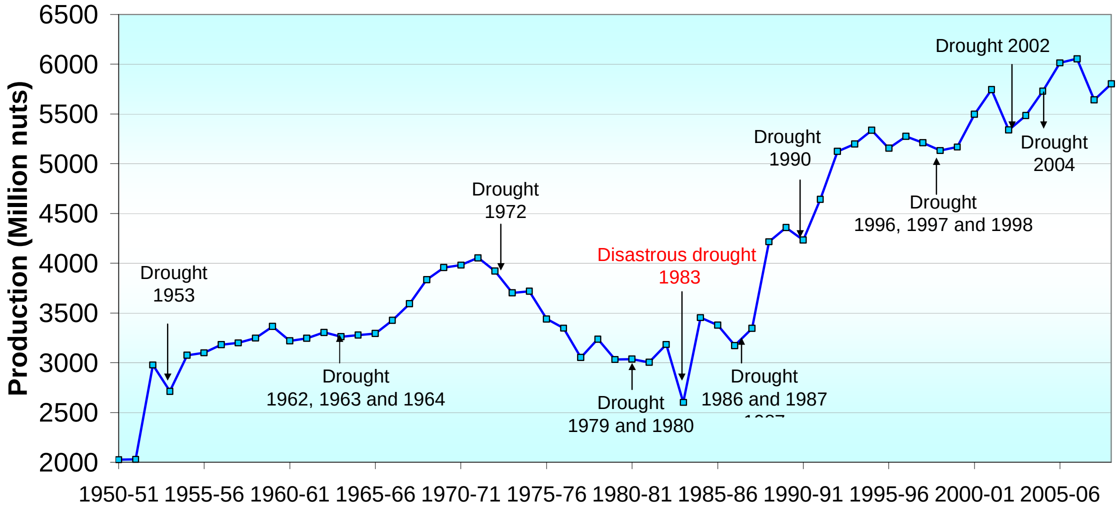


Fig. 5.4: Effect of droughts on coconut production

5.3.4 Impact of droughts on coconut productivity

The decline in coconut productivity of Kerala was maximum during 1983-84 (19.2%) when compared to previous year. The decline in productivity due to summer drought during 1952-53 (Severe), 1971-72 (Severe), 1978-79 (Moderate), 1989-90 (Severe) and 2002-03 (Moderate) was 10.8%, 5.2%, 6.9%, 7.1% and 3.6% respectively (Fig.5.5).

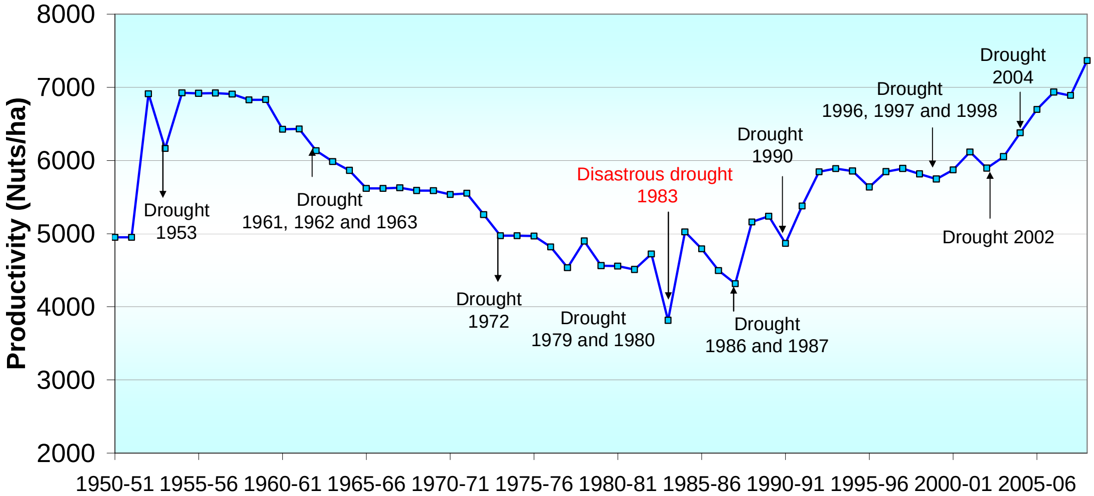


Fig. 5.5: Effect of droughts on coconut productivity

Majority of drought years showed decline in productivity in the following year when compared to previous years. The average decline in coconut productivity of the following year varied between 3.6 to 19%. The decadal coconut production was low (3.01 billion nuts) during 1951-60, followed by 1971-80 (3.45 billion nuts), 1981-90 (3.49 billion nuts), 1961-70 (3.52 billion nuts) and 1991-00 (5.17 billion nuts) while maximum (5.73 billion nuts) in 2001-08 (Fig. 5.6). The low decadal production during 1981-90 is mainly attributed to more number of droughts experienced during that period.

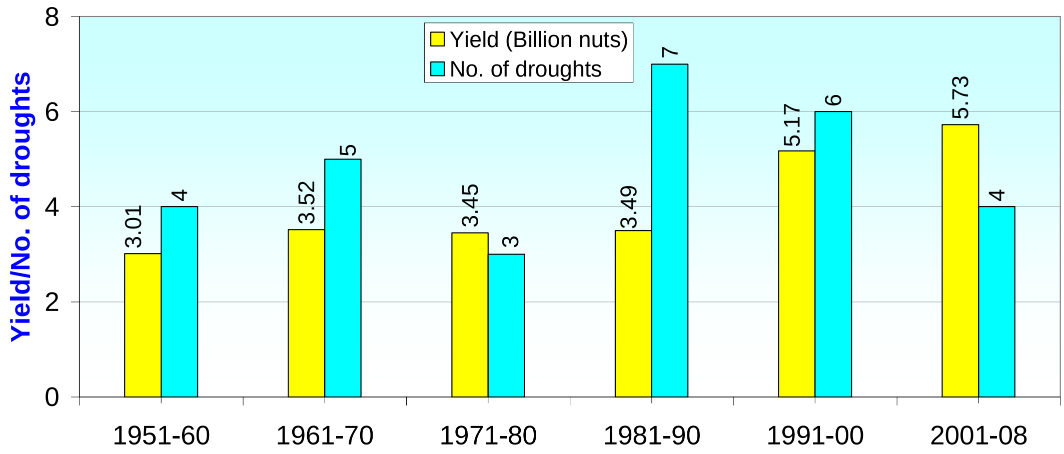


Fig. 5.6: Decade-wise number of droughts versus coconut production

The three decadal average number of droughts were more in 1981-08 and the coconut production was 4.8 billion nuts (Fig. 5.7). The number of droughts have increased to 50% in 1981-2008 when compared to 1951-80 and the yield was increased only 45%.

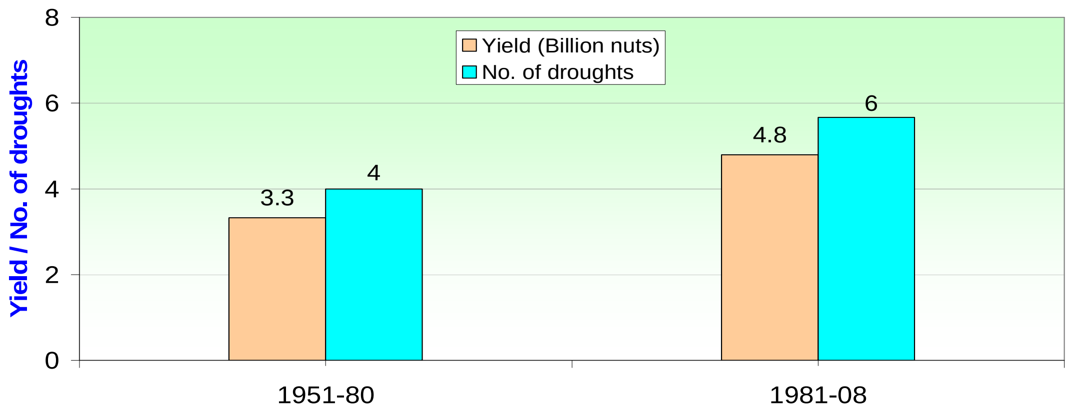


Fig. 5.7: The tri - decadal wise number of droughts versus coconut production

The northern part of Kerala experienced severe soil moisture stress from December to May. Failure of Northeast monsoon and lack of summer showers lead to severe drought situation. Therefore, summer droughts were worked out considering rainfall from December to May at RARS, Pilicode, Kasaragod districts. Based on the above criteria, intensity of summer droughts was worked out for the period from 1983 to 2008. Out of 13 drought years, 5 each fell under moderate and large, 2 fell under severe drought and only one under the extreme drought (Table 5.2).

Table 5.2: Occurrence and intensity of summer droughts at RARS, Pilicode from 1983 to 2008

Decade	Intensity and occurrence of droughts					
	Moderate	Large	Severe	Disastrous	Total	%
1983-90	1	1	1	1	4	50
1991-00	2	3	1		6	60
2001-08	2	1			3	37.5
Total	5	5	2	1	13	
Drought Intensity (%)	38.5	38.5	15.3	7.7		

The percentage occurrence of moderate and large droughts was more (38.5%) at RARS, Pilicode, followed by the category of severe (15.3%) and Disastrous (7.7%). As a whole, 50% of the years experienced summer drought conditions. It is evident that the coconut crop is grown in the low and mid lands of Kasaragod district under severe soil moisture stress in almost half of the years. It was probably one of the reasons, why the fluctuations in coconut production were significant from year to year. The decline in coconut yield during the subsequent year due to disastrous drought year 1982-83 at RARS, Pilicode was 47.8%. The decline in coconut yield during subsequent year in 1988-89 and 1992-93 was 49.8 and 46.8% respectively. While due to large drought during 1985-86, 1990-91, 1997-98 and 2003-04 the yield reduction in the following year was 44.1%, 43.8%, 18.9 and 1.7% respectively. If the intensity of drought is low Viz., large and moderate, the decline in nut yield during the subsequent year is not definite and the yield decline did not exhibit in all the subsequent years unlike in the case of disastrous drought years (Rao *et al.*, 1994). There is a lag period between the influence of weather and crop yield as the phenology of coconut takes 44 months before the final harvest. However, the duration of prolonged dry spells from November to May adversely affect the coconut production in the following year under the field conditions.

5.4 THE EFFECT OF DROUGHTS ON MONTHLY NUT YIELD

The monthly coconut production at RARS, Pilicode, CPCRI, Kasaragod, Aralam farm, Kannur, CDB, Farm, Vellanikkara, RARS, Kumarakom and CRS, Balaramapuram were collected for analyzing the effect drought on monthly yield. The mean monthly maximum coconut production at CPCRI, Farm was observed during the month of May followed by June, March, April and July while the monthly coconut production was lowest in the month of September. Seasonal coconut production was found maximum during summer followed by southwest and post monsoon season while the lowest seasonal production was observed during winter (Fig. 5.8). At RARS, Pilicode maximum monthly coconut production was noticed during the month of April followed by May, March, February and June while the monthly production was minimum in the month of December. Mean monthly maximum coconut production was noticed during May at Aralam Farm followed by June, July and August while lowest production was noticed during the month of February followed by January and December. Seasonal coconut production at Aralam, Farm was high during the southwest monsoon season followed by summer season and post monsoon and the minimum seasonal production was noticed during winter season. The mean monthly coconut production at CBD, Farm, Vellanikkara was maximum in April, followed by March, May and June while it was minimum in December, followed by November and October. The study revealed that the coconut production is high during summer while low during post monsoon season and intermediary in southwest monsoon and winter. At RARS, Kumarakom, the monthly coconut production was minimum in September, followed by December, November, January and February while it was maximum in May, followed by April, June, March and July. The seasonal coconut production was maximum during summer (March- May) followed by southwest monsoon while low during winter followed post monsoon season.

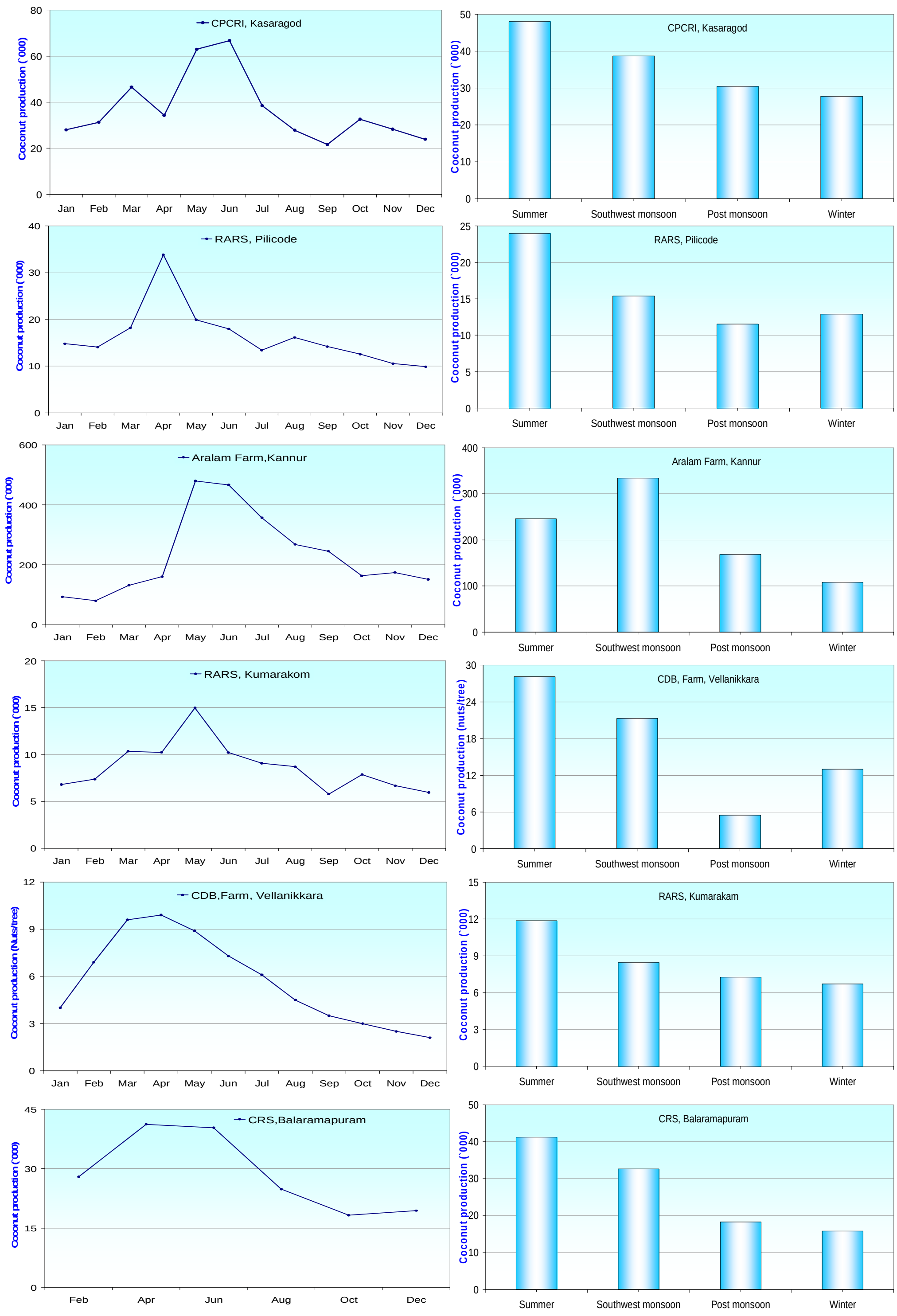


Fig.5.8: Mean monthly and seasonal coconut production at different locations in Kerala

At CRS, Balaramapuram, nut harvest is usually carried out once in two months. Therefore, there were six harvests in a year. The coconut yield was minimum during September - October, followed by November-December, and July-August while it was maximum during March-April, followed by May- June and January - February. The coconut yield during the summer was high followed by southwest monsoon and post monsoon. The minimum coconut production was during the post monsoon and winter season.

5.4.1 Effect of drought on monthly nut yield at RARS, Pilicode

Dry spell was experienced from December 1982 to May, 1983 at RARS, Pilicode. An amount of 9 mm of rainfall was only received in the month of May. So the early withdrawal of northeast monsoon and failure of summer showers led to disastrous condition over the region. The drought period was over in the month of June after the commencement of southwest monsoon. The decline in monthly nut yield against normal was noticed from February 1984 onwards and it continued up to January 1985(Fig. 5.9).

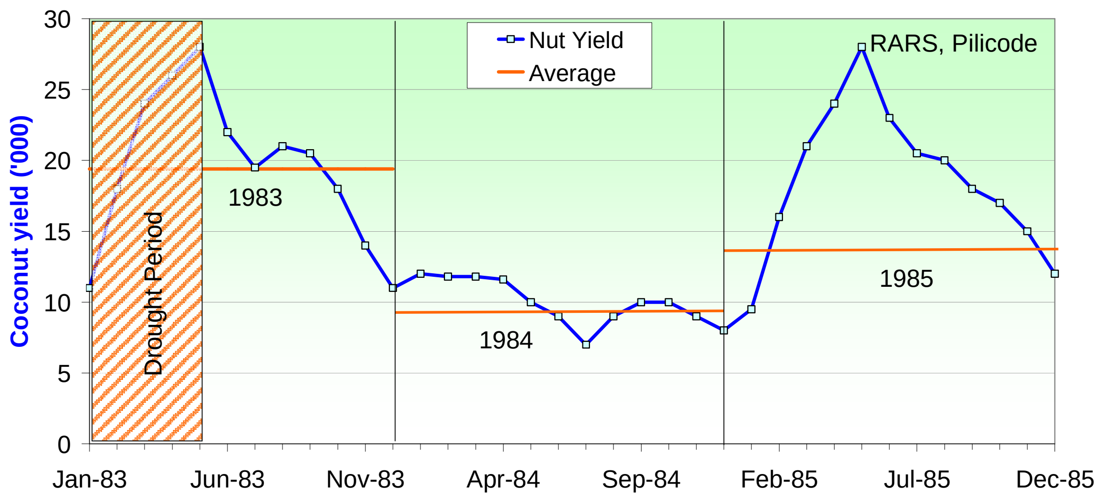


Fig. 5.9: Effect of drought during summer 1983 on coconut yield at RARS, Pilicode

Maximum decline in the monthly nut yield was noticed in the month of July 1984. It revealed that yield reduction was noticed in the following year. The decline in monthly nut yield was noticed from the 8th month after the drought period was over and maximum decline in the yield was noticed in 13th month after the drought period was over and it was continued up to 19th month. Interestingly, the decline in the monthly nut yield varied between 12.3% to 51.9% during the study period.

Again, dry spell was noticed from December 1988 to May 1989. The severe drought period was over by the month of June due to onset of southwest monsoon. Decline in monthly nut was observed from February (8th month) onwards and it continued up to January 1991 (19th month). Maximum yield reduction was noticed in the month of June (12th month) 1990 (Fig. 5.10). The decline in the monthly nut yield varied between 12.8% to 56.4% during the study period. The nut decline due to drought depends upon the different levels of management as well as the intensity of drought.

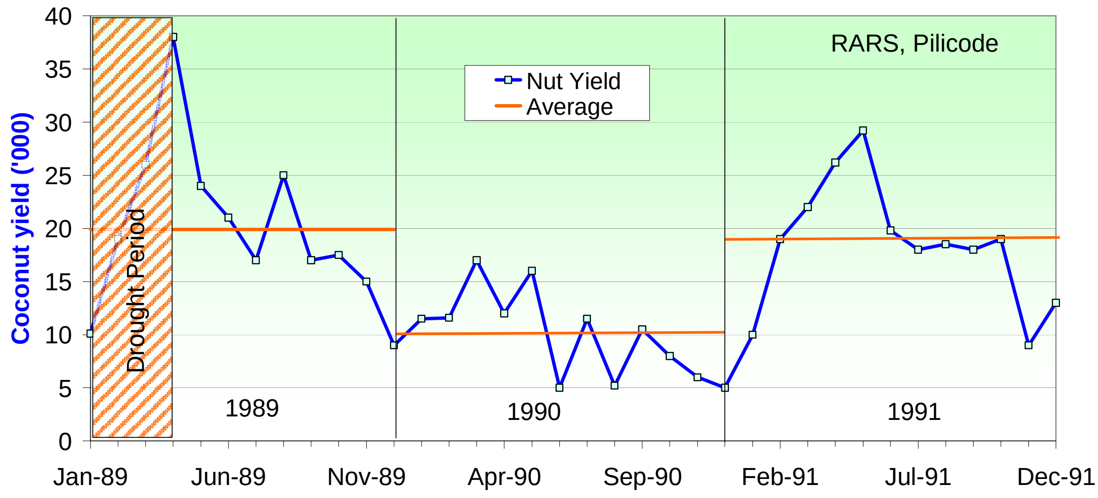


Fig. 5.10: Effect of drought during summer 1989 on coconut yield at RARS, Pilicode

5.4.2 Effect of drought on monthly nut yield at CPCRI, Farm, Kasaragod

Dry spell was experienced from 24.12.1997 to 4.5.1998 at CPCRI Farm Kasaragod. It led to severe drought condition over the region. The drought period was over by the month of May due to pre monsoon showers (255.2mm). The yield decline was seen during the month of January (8th month after the drought period) 1999 onwards and it continued up to March 2000 (22nd month after the drought period). The maximum reduction in monthly nut yield was noticed in the month of July, 14th month after the drought period was over (Fig. 5.11). The decline in the monthly nut yield varied between 11.2% to 82.6% during the study period.

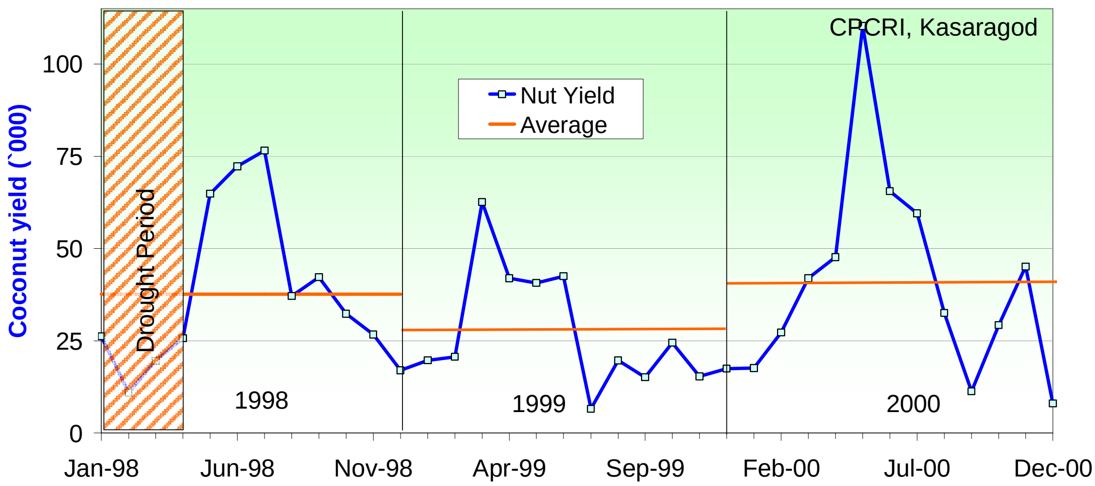


Fig. 5.11: Effect of drought during summer 1998 on coconut yield at CPCRI, Farm, Kasaragod

5.4.3 Effect of drought on monthly nut yield at Aralam, Farm, Kannur

Dry spell was experienced from January to May, 1998 at Aralam Farm Kannur. The drought period was over by the month of June. The yield decline was noticed during the month of March (9th month after the drought period) 1999 onwards and it continued up to March 2000 (21st month after the drought period). The maximum reduction in monthly nut yield was noticed in the month of August, 14th month after the drought period was over (Fig.5.12). The decline in the monthly nut yield varied between 1.5 % - and 51.5% during the study period.

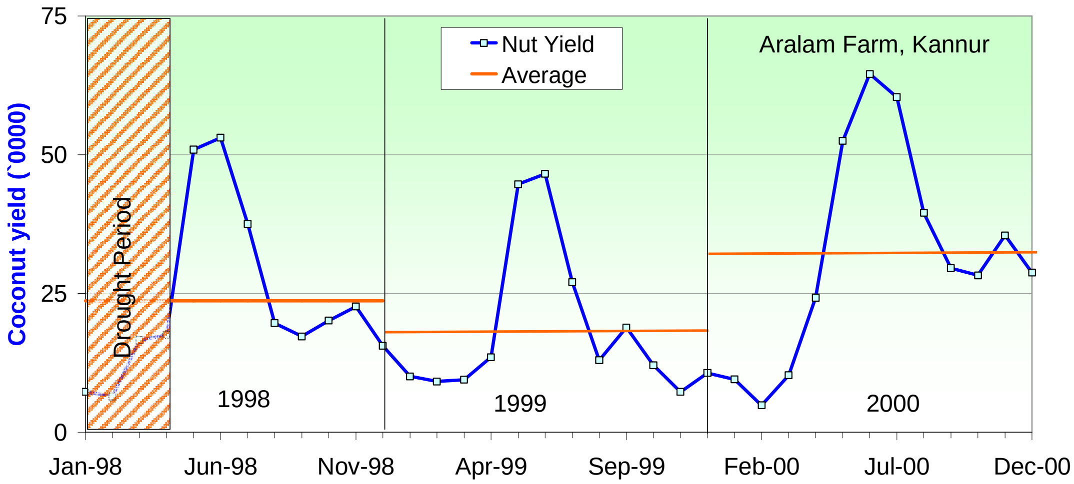


Fig.5.12: Effect of drought during summer 1998 on coconut yield at Aralam Farm, Kannur

5.4.4 Effect of drought on monthly nut yield at CDB, Farm, Vellanikkara

Dry spell was experienced from December 2001 to March, 2002 and intermittent light rainfall in the month March and April at CDB, Farm, Vellanikkara. Early withdrawal of northeast monsoon and failure of summer showers in March and April led to drought condition over the region. The drought period was over in the month of May due the good amount of summer showers received in May (308.4mm). The yield reduction was seen in the following year due to summer drought. It is interesting to note that the decline in nut production was noticed in 2003 January onwards. Decline in nut production was started in the 8th month after the drought period was over and it continued up to December 2003. Maximum decline in the monthly nut yield was noticed in the month of June 2003 (Fig.5.13). It revealed that yield reduction was noticed in the following year from eighth month onwards, maximum reduction was seen in the 13th month and decline in yield continued up to 18th month after the drought period was over. Interestingly, the decline in the monthly nut yield was varied between 13.8% and 31.5% during the study period.

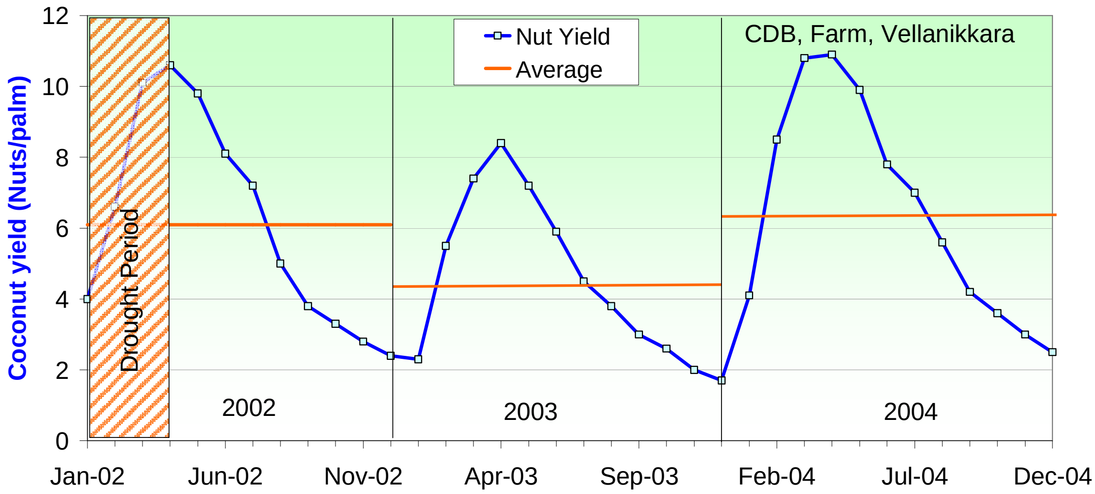


Fig.5.13: Effect of drought during summer 2002 on coconut yield at CDB Farm, Vellanikkara

Similar was the case in summer drought during 2004 with the dry spell, begining from 2nd November and it continued up to 29.3.2004. Intermittent rainfall received in the month of April. So the severe drought condition extended up to April and the drought period was ended with good summer showers in the month of May (578.3mm). Decline in yield reduction was noticed in the 8th month onwards and maximum reduction was seen in the 13th month and the yield reduction continued up to 18th month after the drought period was over (Fig.5.14). The decline in the monthly nut yield varied between 16.4% and 32.9% during the study period.

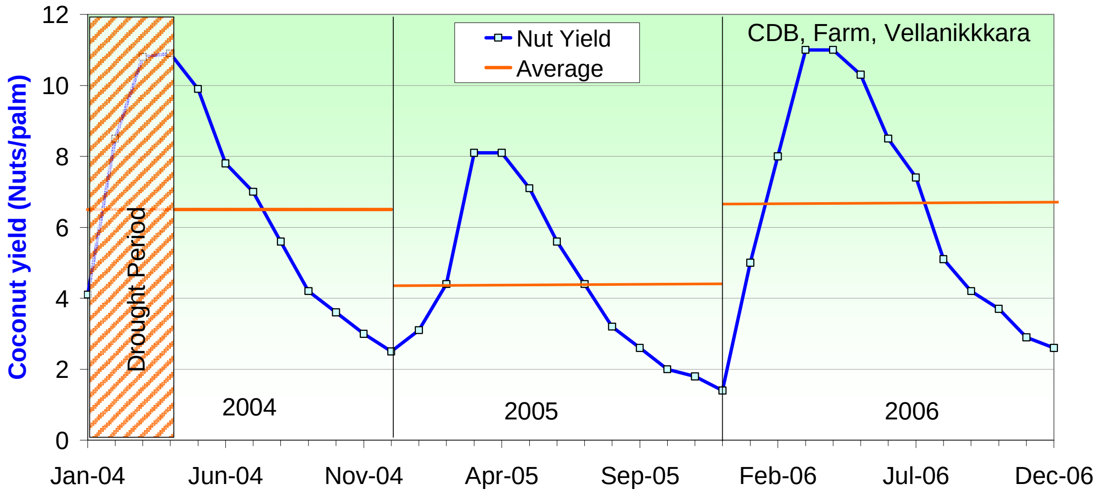


Fig. 5.14: Effect of drought during summer 2004 on coconut yield at CDB, Farm, Vellanikkara

5.4.5 Effect of drought on monthly nut yield at RARS, Kumarakom

Dry spell was experienced from January to April during 1983 at RARS, Kumarakom. An amount of 18.4 mm of rainfall was only received in the month of May. The dry period was over in the month of June after the commencement of southwest monsoon. The decline in monthly nut yield was noticed from January (7^{th} month) 1984 onwards and it continued up to November 1984 (Fig.5.15).

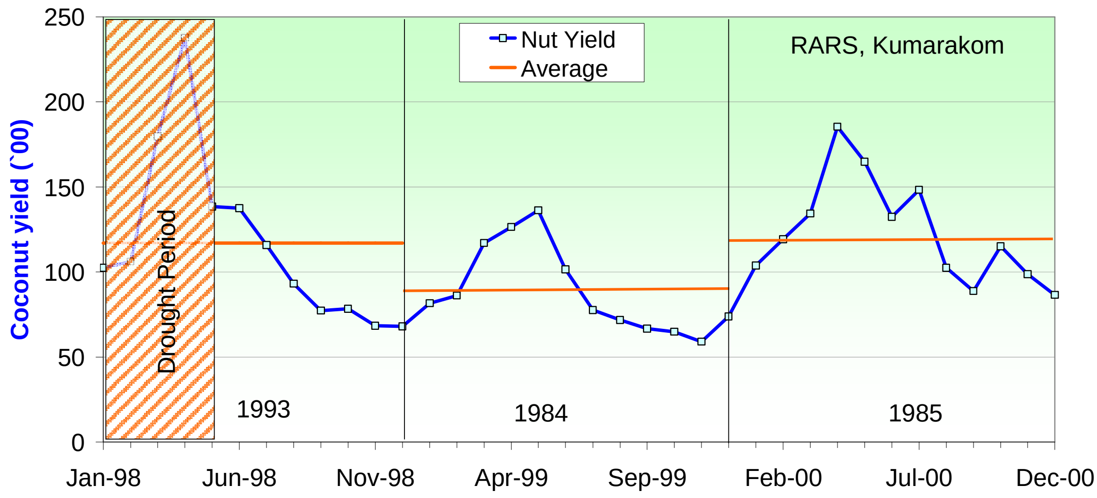


Fig. 5.15: Effect of drought during summer 1983 on coconut yield at RARS, Kumarakom

Maximum decline in the monthly nut yield was noticed in the month of July, 1984 (13th month after the dry period was over). The decline in the monthly nut yield varied between 13.6% and 35.7% during the study period.

5.4.6 Effect of drought on monthly nut yield at CRS, Balaramapuram

Severe soil moisture stress was experienced during the summer 1983. The drought period was over by the month of May. Since the coconut harvest is practiced once in two months, starting from February, only six harvests were done normally in a year. The decline in yield was noticed from January to February harvest during 1984 onwards and it continued up to Mar - April 1985 (Fig.5.16).

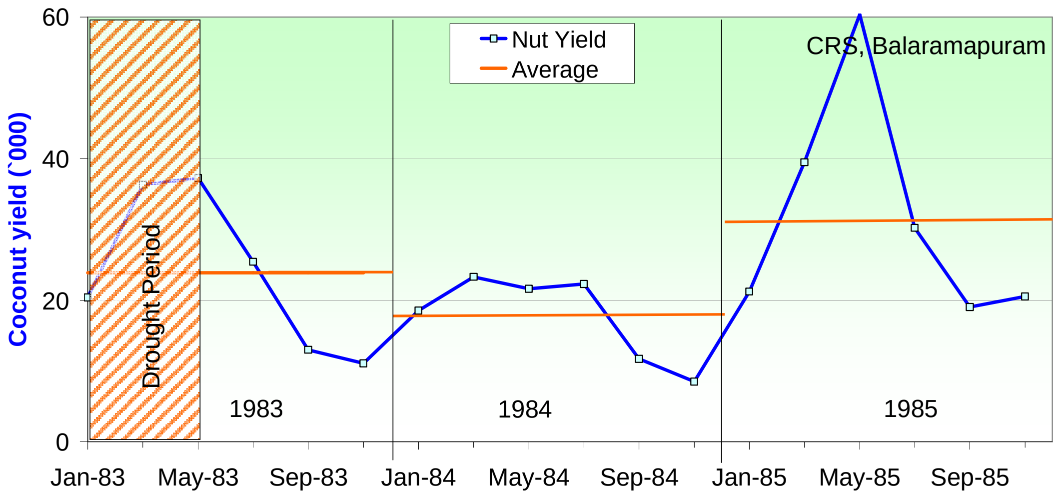


Fig.5.16: Effect of drought during summer 1983 on coconut yield at CRS, Balaramapuram

Maximum reduction was noticed in November - December. Decline in nut yield varied between 4.2 and 56.3%. Similar was the case in summer 1989. The decline in yield was seen in January-February, 1990 and it continued up to November-December, 1990. The maximum reduction was noticed during November - December (Fig.5.17). Decline in nut yield varied between 10.3 and 51.3%.

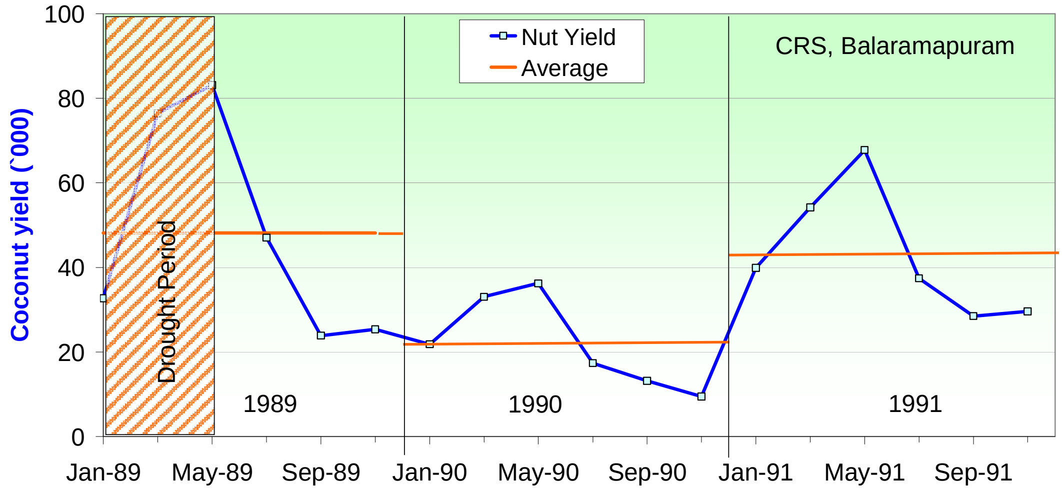


Fig. 5.17: Effect of drought during summer 1989 on coconut yield at CRS, Balaramapuram

The summer drought normally ends by June with the commencement of onset of monsoon. During 1983, the onset of monsoon was on 13th June. The early withdrawal of northeast monsoon in 1982 followed by delayed monsoon in 1983 prolonged the drought period. It resulted in low coconut production in the subsequent year, that was in 1984. The results indicated that the effect of drought on coconut yield was seen in the following year though the reproductive phase from the initiation of primordium to nut harvest takes about three - and -a- half years. Similar was the case in such summer drought years of 1989, 1998, 2002 and 2004 in various locations of the State.

On examination of the effect of drought on monthly nut yield at various locations across Kerala, it is understood that the effect of drought on monthly nut yield commenced in the seventh, eighth or ninth month after the drought period was over in May or June, depending upon the receipt of pre-monsoon showers or onset of monsoon. The effect of summer drought on coconut yield continued for a period of twelve months. It revealed that the effect of drought on monthly yield commenced between January and March after the drought period was over with the commencement of onset of monsoon and continued till January /February of the following year. It was the reason why the effect of drought on coconut yield is seen in the following year. The maximum decline in monthly nut yield was maximum in 12^{th} /13^{th} month after the drought period was over (Table 5.3).

Table 5.3: Effect of drought on coconut yield at different locations in Kerala

Sl. No	Name of the station	Drought period and duration	Effect of drought on monthly nut yield			
			Effect of drought on monthly coconut yield	Minimum decline in monthly yield	Maximum decline in monthly yield	Average decline in yield (%)
1	RARS, Pilicode	December 1982 to May, 1983 (6 months)	Feb (8^{th} month), 1984 to January, 1985 (19^{th} month)	12.3% (January, 1985)	51.8% (July1984) 13^{th} month	33.2
		December 1988 to May 1989 (6 months)	Feb (8^{th} month),1990 to January 1991 (19^{th} month)	12.8% (March, 1990)	56.4% (June 1990) 12^{th} month	34.3
2	CPCRI, Farm, Kasaragod	January to April,1998 (4 months)	Jan (8^{th} month) 1999 to March 2000 (22^{nd} month)	11.2% (March 2000)	82.6% (July199) 14^{th} month	25.6
3	Aralam, Farm, Kannur	December 1997 to May1998 (6 months)	March (9^{th} month) 1999 to March 2000 (21^{st} month)	1.5% (June 1999	51.5% August 1999 14^{th} month	24.7
4	CDB, Farm, Vellanikkara	December 2001 to April 2002 (5 months)	Jan, 2003 (8^{th} month) to Dec, 2003 (18^{th} month)	13.2% April 2003	31.5% June 2003 13^{th} month	20.6
		December 2003 to April 2004 (5 months)	Jan, 2005 (8^{th} month) to Dec, 2005 (18^{th} month)	16.4% March 2005	32.9% June 2005 13^{th} month	24.4
5	RARS, Kumarakom	December 1982 to May, 1983 (6 months)	Jan, 1984(7^{th} month) to Nov, 1984 (19^{th} month)	13.6% November 1984	16.2% July 1984 13^{th} month	23.4
6	CRS, Balaramapuram	December 1982 to May, 1983 (6 months)	Jan - Feb,1984 ($7/8^{th}$ month) to Mar - Apar,1985 ($22/23^{rd}$ month)	4.2% Mar - Apr 1985	56.3% Nov-Dec 1984 $18/19^{th}$ month	31.8
		December 1988 to May, 1989 (6 months)	Jan-Feb, 1990 ($7/8^{th}$ month) to Nov-Dec, 1990 ($18/19^{th}$ month)	10.3% May-Jun, 1990	51.3% Nov-Dec, 1990 $18/19^{th}$ month	26.9

It also revealed that the effect of drought on coconut yield under the field condition was noticed for a period of 12 to 14 months though the reproductive phase from primordium initiation to nut harvest takes about 44 months. The maximum decline on monthly nut yield varied between 30 and 80 per cent depending upon the management and cultivar across the State of Kerala. Even at Kumarakom, where the coconut palms are grown on bunds under the below mean sea level and the soil moisture in the root zone is not a constraint, the effect of severe atmospheric drought on coconut yield varied between 13 and 26%. As a whole, the effect of drought on coconut yield in the following year varied between 20.6 and 34.3%. Depending upon the yield group in coconut, the effect of summer drought on nut yield varied between 10 and 30% (Rao, 1993). Though the summer droughts are not frequent, it is not uncommon in the northern districts of Kerala, where the area under coconut cultivation is more and grown in rainfed conditions. Therefore, the coconut palm does experience moderate to severe soil moisture stress during summer under rainfed conditions depending upon the receipt of pre monsoon showers or onset of monsoon. The studies also indicated that the effect of drought on coconut yield is likely to be less under better agronomic and crop protection practices. Hence, there is a need to follow pro-active measures for drought management in coconut gardens as their frequency is likely to increase under the projected climate change scenarios. It is also a fact that coconut yield is more vulnerable to such weather events rather than climate change. Of course, the effect of climate change on coconut yield is likely to be indirect rather than direct in the form of climate variability, which is discussed in detail in the next Chapter.

Chapter VI

Climate change and coconut production in Kerala

6.1 RAINFALL

The annual normal rainfall over Kerala from 1871 to 2009 is 2827.8 mm with a standard deviation of 403.6 mm. The dependable annual rainfall at 75 per cent level is 2515 mm and the dependable seasonal rainfall at 75 per cent for summer, southwest monsoon, post monsoon and winter season is 269.4 mm, 1652.0 mm, 341.0 mm and 26.9 mm, respectively (Table 6.1).

Table 6.1: Monthly and seasonal means of rainfall (mm) over Kerala from 1871 to 2009

Month	Rainfall (mm)					
	Normal	Standard deviation	Coefficient of Variation (%)	75% probability	Percentage contribution to annual	Mann-Kendall rank statistics
January	11.0	16.6	151.8	0.4	0.4	1.361015
February	16.8	20.5	121.9	2.8	0.6	1.362395
March	36.7	32.6	88.8	15.5	1.3	1.007002
April	111.3	51.2	46.0	72.6	3.9	1.402146
May	243.7	157.0	64.4	131.1	8.6	0.089226
June	682.4	192.4	28.2	576.7	24.1	-2.64401**
July	638.4	205.4	32.2	509.4	22.6	-1.13081
August	375.5	155.7	41.4	270.8	13.3	0.912292
September	229.1	123.4	53.9	136.3	8.1	1.533236
October	288.9	107.4	37.2	204.5	10.2	1.688024*
November	157.0	85.4	54.4	94.2	5.6	1.669822*
December	37.0	37.8	102.1	9.9	1.3	-0.64463
Annual (mm)	2827.8	403.6	14.3	2515	100.0	-0.11108
Summer	391.7	159.9	40.8	269.4	13.8	0.966923
Southwest monsoon	1925.4	368.6	19.1	1652	68.1	-1.4349
Post - monsoon	445.9	138.1	31.0	341	15.8	2.423674**
Winter	64.1	46.6	72.7	26.9	2.3	0.375511

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

The coefficient of variation of annual rainfall is 14.3%, indicating that it is highly stable. Rainfall during June is the highest (682.4 mm) and contributes to 24.1% of annual rainfall (2827.8 mm), followed by July (22.6%). Rainfall in August and September contributes to 13.3% and 8.1% of the annual rainfall, respectively. Rainfall in January is the least (11.0 mm) and contributes only 0.4% to the annul rainfall. The coefficient of variation is also the highest during January (151.8%), followed by February (121.9%) and December (102.1%) and the least during the high rainfall months of June (28.2%) and July (32.2%). Rainfall during the southwest monsoon (June - September) contributes 68.1 % of the annul rainfall. The contribution of summer (March - May), post monsoon and winter rainfall to the annual is 13.8, 15.8 and 2.3, respectively. The seasonal rainfall during monsoon (June - September) is dependable as the coefficient of variation is 19.1%.

At the same time, rainfall during winter is undependable as the coefficient of variation is very high (72.7%), varying between 102.1 % in December and 151.8 % in January. It is a bi-modal rainfall pattern, experienced in Kerala due to influence of southwest and northeast monsoon seasons (Fig. 6.1). It is more pronounced towards south of Kerala when compared to that of northern districts.

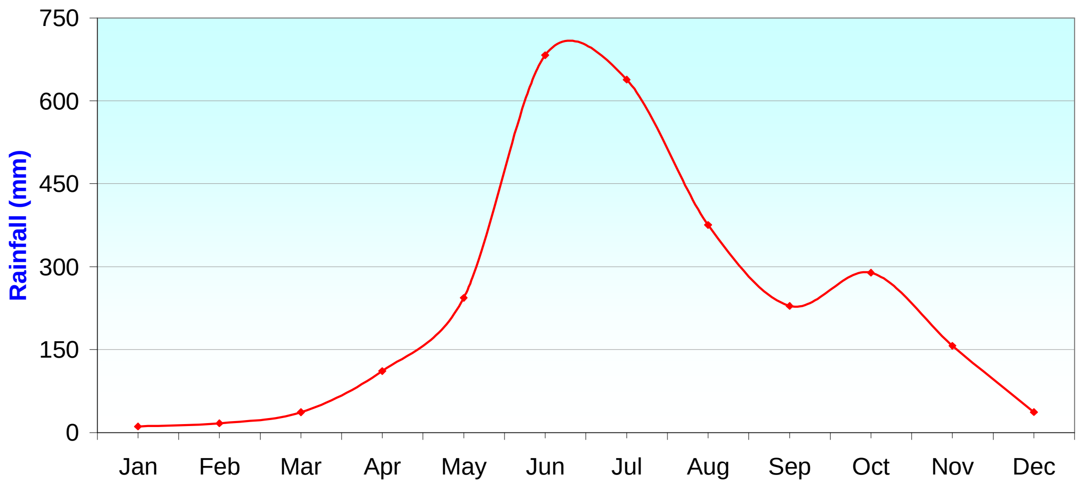


Fig. 6.1: Monthly mean rainfall over Kerala

High monsoon rainfall from June to September followed by moderate dry spell is the characteristic feature of the humid tropics. The monsoon rains are relatively stable over Kerala "Gate way of Indian monsoon". However, the monsoon rainfall over Kerala during 2002 was one of the lowest, if not the least, less by 33% over the long period average (Table 6.2).

Table 6.2: Percentage deviation of southwest monsoon rainfall over Kerala

Year	June	July	August	September	June-Sept.
2001	-11.9	-26.6	-20.3	38.4	-12.4
2002	-23.0	-58.8	9.1	-58.8	-32.9
2003	-10.3	-11.7	-10.7	-69.6	-17.9
2004	-15.3	-41.5	-26.3	-29.1	-27.8
2005	-9.8	1.7	-50.0	23.8	-9.8
2006	-12.7	-12.9	2.8	92.5	2.8
2007	2.9	40.3	11.5	98.4	28.3
2008	-39.5	-7.5	-24.5	42.5	-16.2
2009	-36.4	27.1	-31.8	35.6	-5.9
2010	-2.0	-1.3	-4.7	19.6	0.4

Out of 14 districts, 12 districts received deficit rainfall. The percentage deviation of monsoon rainfall over Kerala from 2001 to 2010 indicated that the deficit rainfall during monsoon varied from 5.9 to 32.9% over the normal except in 2007. The year 2007 was the only year during which the monsoon rainfall was very high (28.3%) against the normal and led to floods in low lying areas. In view of the importance of climate change/variability, as indicated above, it would be of interest to study the long-term variation of monthly, annual and seasonal temperature, rainfall and its impacts on coconut.

6.1.1 Annual rainfall trends

The annual rainfall over Kerala was declining though it was not significant. A decrease of 11.5 mm only was noticed during the study period of 139 years as against the normal rainfall of 2827.8 mm. A sort of cyclic trend was noticed for 30 - 40 years. Accordingly, the annual rainfall is likely to increase in the ensuing years (Fig. 6.2). The annul rainfall was below normal from 1871 to 1900 followed by wet period. After 1980 the annual rainfall again showed continuously below normal, indicating that the annual rainfall was decreasing in recent years.

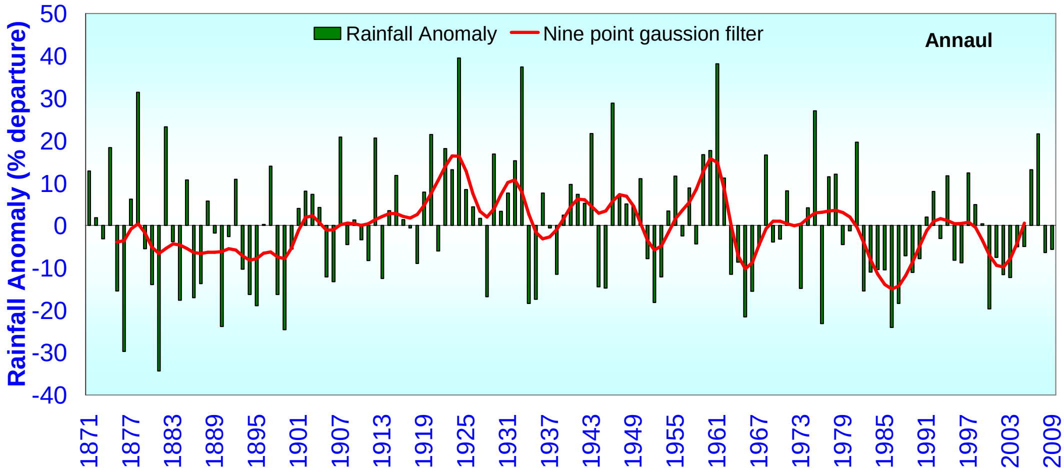


Fig. 6.2: Annual rainfall over Kerala and its nine point Gaussian filter

6.1.2 Seasonal rainfall trends

The seasonal rainfall indicated that there was a significant increase in post monsoon season, that is rainfall in October and November. Similar trend was noticed in winter and summer rainfall though not significant. It may be an indication of rainfall shift as monsoon rainfall was so erratic in recent years and the trend line in rainfall during southwest monsoon was declining though not significant. The rainfall anomaly and its nine point Gaussian filter indicate that the seasonal and temporal oscillations in rainfall are predominant. As seen in the case of annual rainfall, the seasonal rainfall was also low between 1871 and 1900, followed by wet years and thereafter decreasing in recent decades. It was seen in all the seasons (Fig. 6.3).

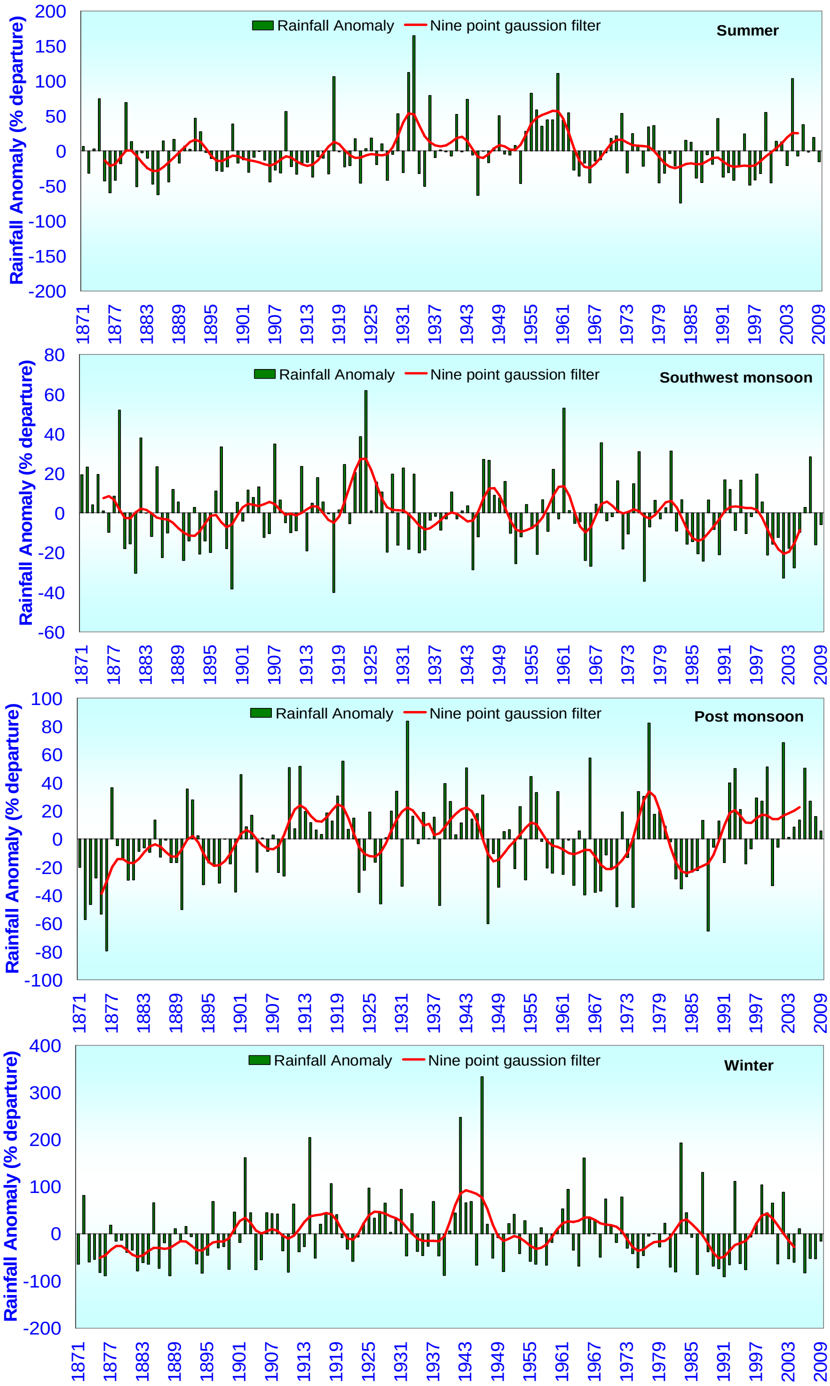


Fig.6.3: Seasonal rainfall over Kerala and its nine point Gaussian filter

6.1.3 Monthly rainfall trends

The trends in monthly rainfall indicates that increase in rainfall was noticed during October and November while decrease in the rainiest month, June. In remaining months, the trends are not significant. As seen in the case of seasonal rainfall, monthly rainfall oscillations were also predominant. The monthly rainfall was also low from 1871-1900, followed by wet spell and in recent years, it was increasing in June, October and November. A significant decrease in monthly rainfall was noticed in June while increase in October and November (Fig.6.4). The contribution of monthly rainfall to annual was also declining in June and July while increasing in August, September, October and December.

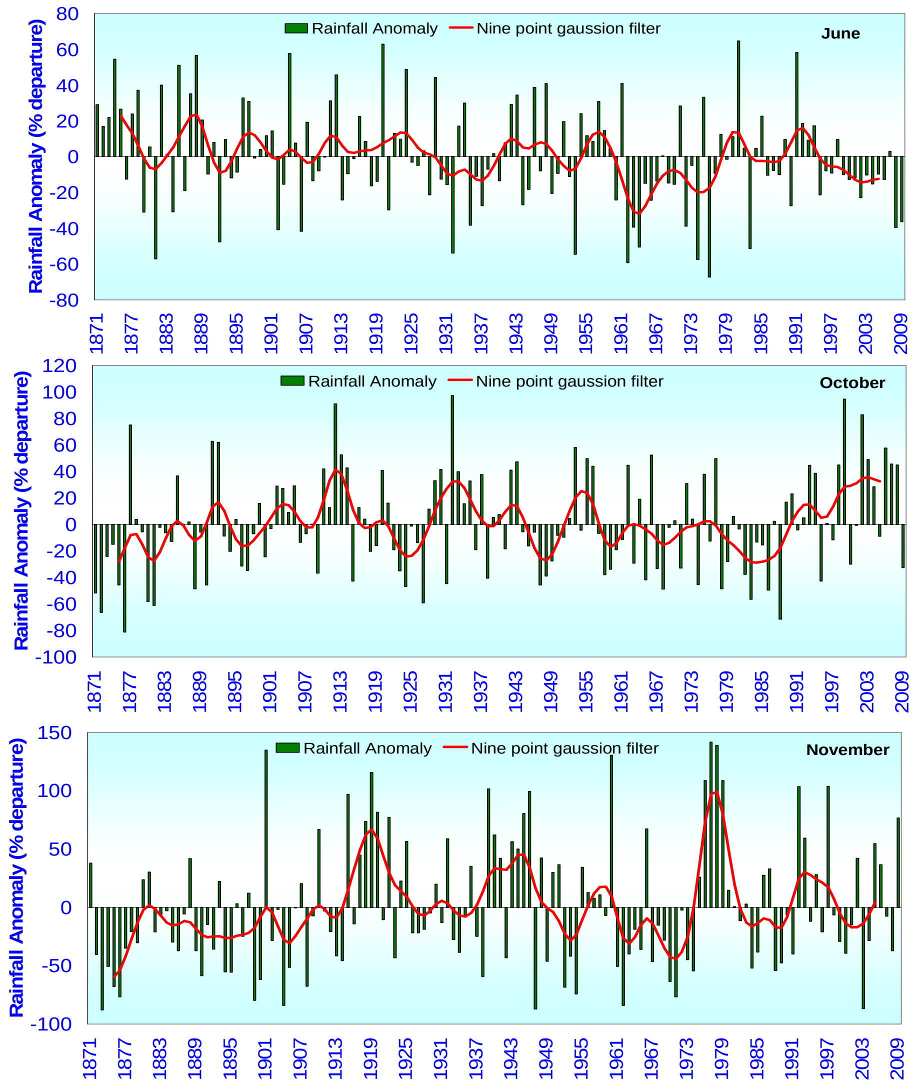


Fig.6.4: Monthly rainfall anomaly over Kerala and its nine point Gaussian filter

6.2 TEMPERATURE FEATURES

The annual mean maximum temperature over Kerala from 1956 to 2009 is 31.8°C while mean minimum temperature is 23.4°C. The mean monthly maximum temperature was high (34.5°C) in March while July witnessed a low (29.2°C). The mean monthly minimum temperature was low (21.7°C) during January while the minimum temperature was high (25.1°C) in April. The mean monthly temperature was high (29.7°C) in April while it was low (26.1°C) in July (Table 6.3).

Table 6.3: Monthly and seasonal temperature means over Kerala from 1956 to 2009

	Temperature (°C)			
	Maximum	Minimum	Mean	Range
January	32.6	21.7	27.2	10.8
February	33.6	22.6	28.1	10.9
March	34.5	24.2	29.4	10.4
April	34.3	25.1	29.7	9.2
May	32.9	24.9	28.9	8.0
June	30.1	23.6	26.9	6.6
July	29.2	23.0	26.1	6.1
August	29.4	23.2	26.3	6.2
September	30.4	23.4	26.9	7.0
October	31.0	23.4	27.2	7.6
November	31.5	23.1	27.3	8.5
December	32.1	22.2	27.1	9.9
Annual (mm)	31.8	23.4	27.6	8.4
Summer	33.9	24.7	29.3	9.2
Southwest monsoon	29.8	23.3	26.5	6.5
Post - monsoon	31.3	23.2	27.2	8.0
Winter	32.7	22.2	27.5	10.6

The maximum temperature was high (33.9°C) during summer while low (29.8°C) in southwest monsoon. The mean surface air temperature also showed similar seasonal trend as in the case of maximum temperature. In the case of minimum temperature, it was high (24.7 °C) during summer while it was low (22.2°C) in winter. The temperature range was highest (10.6°C) in winter and least (6.5°C) in southwest monsoon. It is a peculiar phenomenon where the monsoon is predominant (Fig. 6.5).

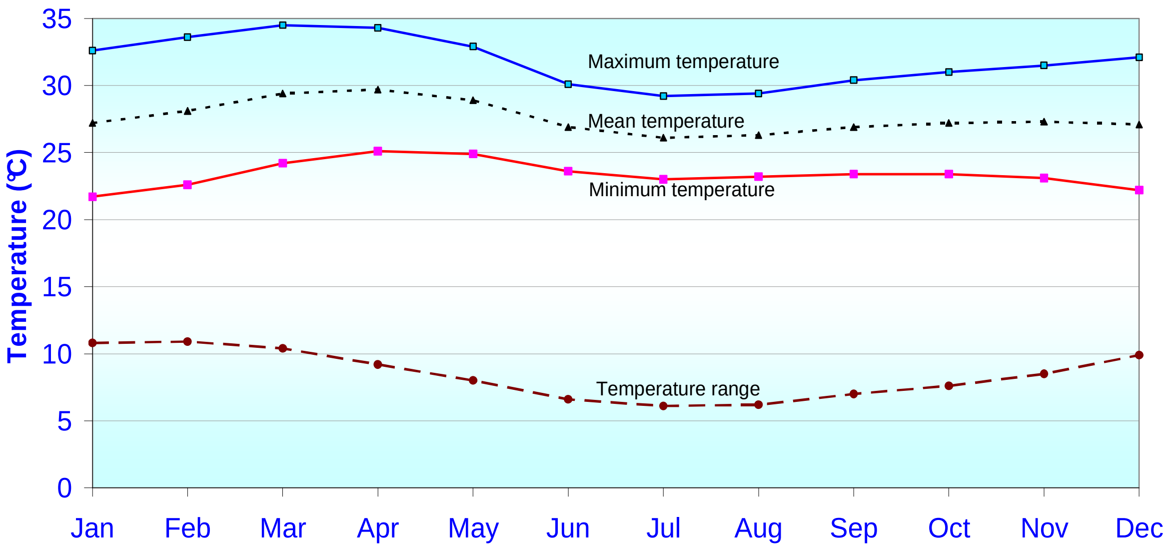


Fig. 6.5: Monthly mean maximum, minimum, mean temperature and temperature range over Kerala

6.2.1 Annual and seasonal temperature trends

The annual maximum temperature over Kerala has increased by 0.72°C over a period of 54 years from 1956 to 2009 and the minimum temperature by 0.22°C during the same period. The increase in mean temperature was 0.47°C during the study period from 1956 to 2009. The trend in maximum, minimum and mean temperature showed an increasing trend, indicating that warming Kerala is real due to climate change. The increasing trend was also noticed in temperature range, that is the difference between maximum and minimum temperatures (Fig. 6.6).

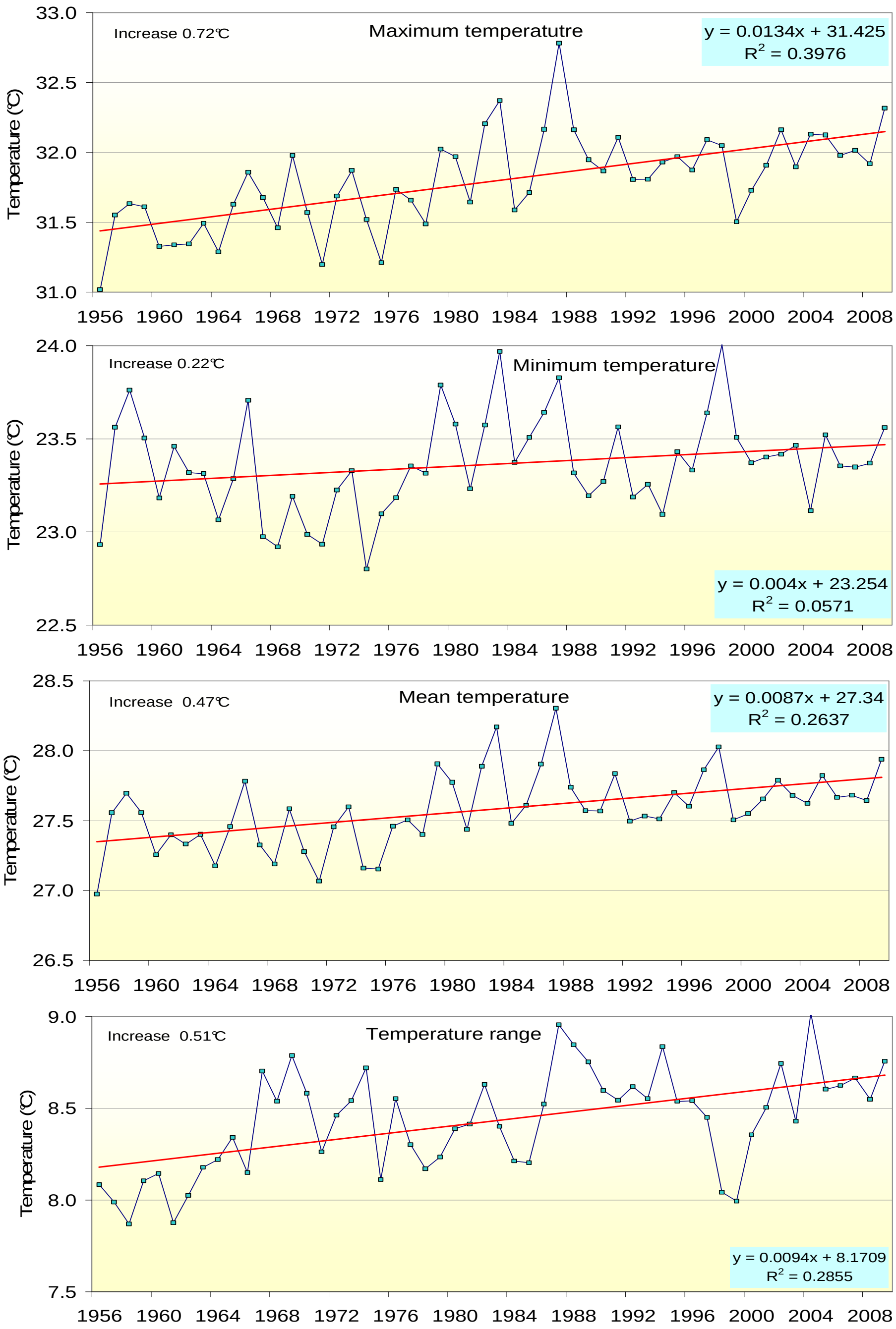


Fig. 6.6: Trends in maximum, minimum, mean and temperature range over Kerala

The warming Kerala is more predominant since 1980, as seen in temperature anomaly with its 21 point binomial filter (Fig. 6.7).

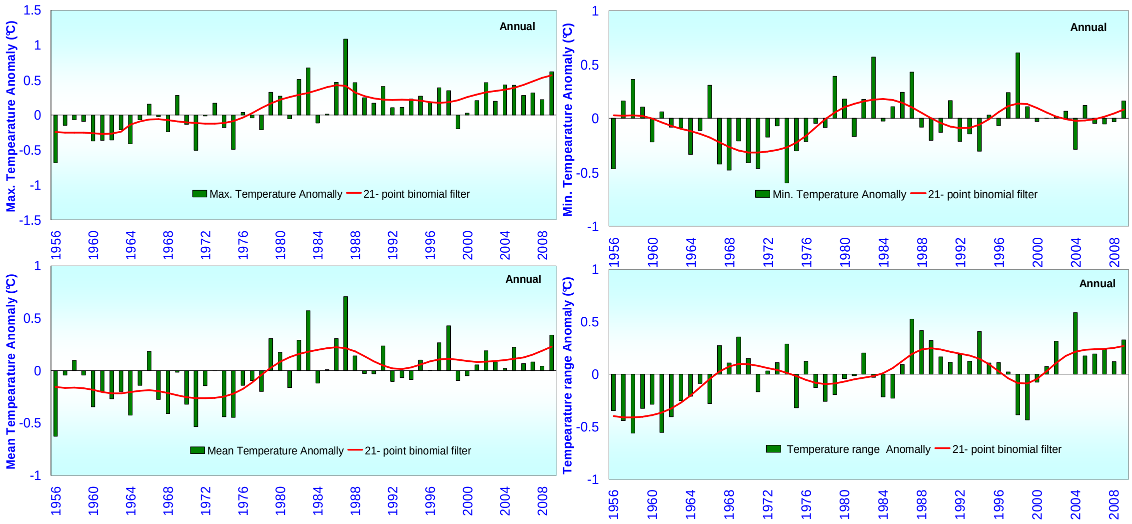


Fig.6.7: Annual temperature anomalies and its 21 point binomial filter

Increase in temperature is more evident during southwest monsoon season when compared to that of the other seasons (Fig.6.8). It was attributed to decline in monsoon rainfall in recent years, resulting in high temperature.

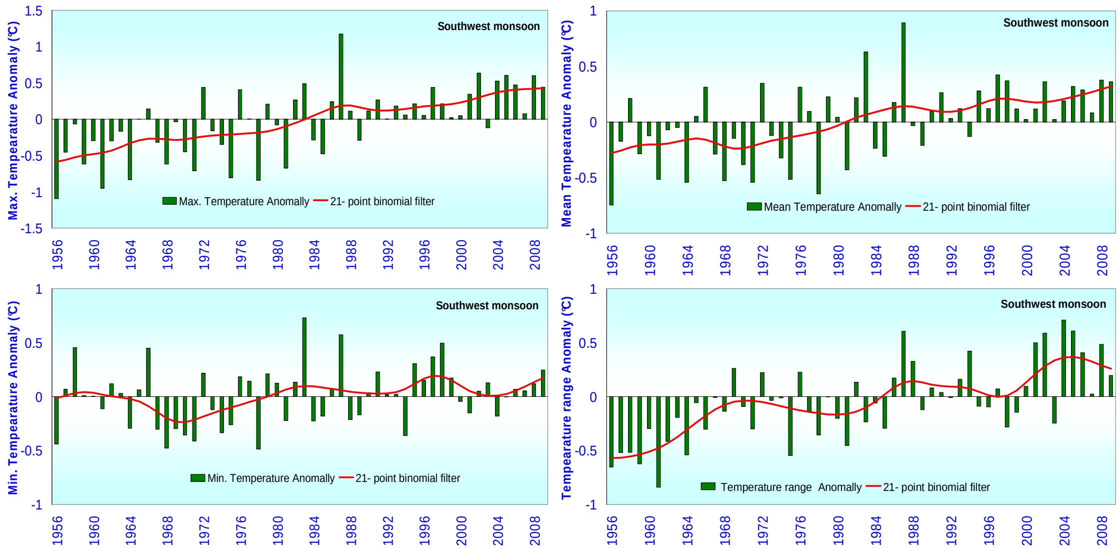


Fig.6.8: Temperature anomalies and its 21 point Gaussian filter during southwest monsoon season

6.2.2 Monthly temperature trends

The monthly maximum temperature showed significant increasing trend in all the months except April. In the case of minimum temperature, only July month showed significant increasing trend while in the reaming months the trend was not statistically significant (Table 6.4).

Table 6.4: Mann-Kendall rank statistics of monthly mean temperatures over Kerala

Month/season	Temperature			
	Maximum	Minimum	Mean	Range
January	3.1192**	-0.1786	0.7207	1.1928
February	2.4029**	-0.1021	0.6442	0.8485
March	2.3135**	-0.5167	0.6378	1.5945
April	1.0148	-1.2185	0.0383	2.8964**
May	2.6264**	-0.1595	1.1226	3.7571**
June	2.6192**	0.8292	2.7491**	4.0889**
July	4.3207**	2.1818*	4.1589**	5.3071**
August	4.5890**	0.8548	3.8400**	5.0212**
September	3.5367**	1.1609	2.9595**	3.2535**
October	2.9246**	0.3189	2.8127**	4.4396**
November	2.2534*	0.8420	2.2069*	4.4396**
December	3.0516**	0.1403	1.9071*	1.5500
Annual (mm)	4.9910**	0.5102	3.4823**	1.5500
Summer	2.5593**	-0.5804	0.7654	5.1088**
Southwest monsoon	4.9764**	1.5052	4.3118**	4.0439**
Post - monsoon	3.3873**	0.9376	2.8573**	3.3933**
Winter	2.9533**	-0.0850	1.0005	1.6872*

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

The mean temperature during June, July, August, September, October, November and December showed significant increasing trend while in the remaining months, trends were not significant. Trend in temperature range also showed increasing from January to December. The trend in temperature range during January, February, March and December was not significant while remaining months showed significant increasing trend. Linear trend (Table 6.5) indicated that increase in monthly maximum temperature varied between 0.12°C (April - 0.0023°C/year) to 1.14°C (May - 0.0206°C/year) while trend in minimum temperature varied between 0.02 (April - 0.0004°C/year) to 0.43°C

(January - 0.0079°C/year) over a period 54 years. The highest increase in maximum temperature was noticed in May (1.14°C each) while the lowest (0.12°C) was in April. Decadal and tri-decadal changes in temperature followed the same trend.

Table 6.5: Trends in monthly maximum, minimum, mean and temperature range over Kerala

	Temperature (°C/Year)				Temperature (°C/Decade)				Temperature (°C/30Year)			
	Max	Min	Mean	Range	Max	Min	Mean	Range	Max	Min	Mean	Range
January	0.0105	0.0079	0.0092	0.0027	0.0708	0.0518	0.0613	0.0190	0.3297	0.2598	0.2948	0.0699
February	0.0071	0.0066	0.0068	0.0005	0.0552	0.0376	0.0464	0.0176	0.2309	0.1458	0.1884	0.0851
March	0.0065	0.0027	0.0046	0.0038	0.0552	0.0126	0.0339	0.0427	0.2242	0.0411	0.1327	0.1831
April	0.0023	0.0004	0.0014	0.0019	0.0380	0.0082	0.0231	0.0297	0.1281	0.0171	0.0555	0.1452
May	0.0206	0.0046	0.0126	0.0160	0.2394	0.0512	0.1453	0.1882	0.4647	0.0721	0.2684	0.3926
June	0.0165	0.0026	0.0095	0.0139	0.1690	0.0152	0.0921	0.1537	0.5045	0.1280	0.3163	0.3764
July	0.0187	0.0042	0.0115	0.0145	0.1759	0.0276	0.1018	0.1483	0.5704	0.1321	0.3512	0.4383
August	0.0194	0.0040	0.0117	0.0154	0.1676	0.0249	0.0963	0.1427	0.5562	0.1418	0.3490	0.4144
September	0.0205	0.0049	0.0127	0.0155	0.2044	0.0436	0.1240	0.1609	0.5894	0.1394	0.3644	0.4500
October	0.0170	0.0035	0.0103	0.0135	0.1611	0.0174	0.0892	0.1437	0.4528	0.1566	0.3047	0.2962
November	0.0106	0.0047	0.0076	0.0058	0.118	0.0257	0.0719	0.0924	0.2895	0.1141	0.2018	0.1754
December	0.0113	0.0016	0.0065	0.0098	0.086	0.0029	0.0415	0.0889	0.3236	0.0118	0.1677	0.3119

The highest (0.43°C) increase in minimum temperature was observed in January, while the lowest (0.02°C) in April during 1956-2009. In the case of mean temperature, the highest increase was noticed in September (0.69°C), while the lowest (0.08°C) was in April. Temperature range was the highest in May (0.86°C), while the lowest (0.03°C) was in February.

6.2.3 Temperature extremes over Kerala

The annual mean temperature recorded over Kerala was the highest (28.3°C) in 1987 as against the normal of 27.6°C, followed by 28.2 °C in 1983. The highest (32.8°C) annual maximum temperature was also observed in 1987, followed by 32.4°C in 1983 while the lowest annual maximum temperature (31.0°C) was recorded in 1956 as against the average maximum temperature of 31.8°C, The lowest annual mean minimum temperature (22.8°C) was recorded in 1974 (Table 6.6). The average night temperature was high (24.0°C) in 1998 and 1983. The coldest winter of (21.2°C) was observed in

1976, followed by 1974 (21.3°C) as against the mean night temperature of 22.2°C. The warmest (23.4°C) winter was recorded in 1998, followed by 1979 (23.1°C). It is evident that the warmest year was observed in 1987 while the coldest in 1956 over Kerala. The decade 1961-70 and 1971-80 were the coldest (27.4°C) while 1981-90 was the warmest (27.8°C) in Kerala.

Table 6.6: Extreme temperature events over Kerala

Sl. No.	Year	Extreme event	Observed temp.(°C)	Normal temp.(°C)
1	1987	Warmest year	28.3	27.6
2	1983	Second warmest year	28.2	27.6
3	1987	Highest annual max. temperature	32.8	31.8
4	1983	Second highest max. temperature	32.4	31.8
5	1956	Lowest annual mean max. temperature	31.0	31.8
6	1974	Lowest annual mean minimum temperature	22.8	23.4
7	1956	Coldest annual mean temperature	27.0	27.0
8	1987	Hottest summer	35.2	33.9
9	1983	Second hottest summer	35.1	33.9
10	1976	Coldest winter	21.2	22.2
11	1972 1974	Second coldest winter	21.3	22.2
12	1998	Warmest winter	23.4	22.2
13	1979	Second warmest winter	23.1	22.2
14	1980-89	Warmest decade	27.8	27.6

6.3 OCCURRENCE OF CLIMATOLOGICAL DROUGHTS OVER KERALA

The annual aridity index (Fig. 6.9) over Kerala showed a marginal increase (6.1%) since last 109 years (1901-2009). Annual increase in aridity index was significant at 0.05 level. On decade wise (Fig. 6.10), it indicated that the aridity index was high in 1991-2000 (19%) and 1981-90 (18.4%) while it was low in 1941- 50 (14%) and 1951-60 (15%). The three decadal mean of the aridity index showed an increasing trend (1% over a period of 30 years). Increase was more pronounced in the recent tri - decade. The tri- decadal aridity index indicated that there was an increase from 1961 onwards (Fig. 6.11). It is a clear indication of climate change in terms of aridity index.

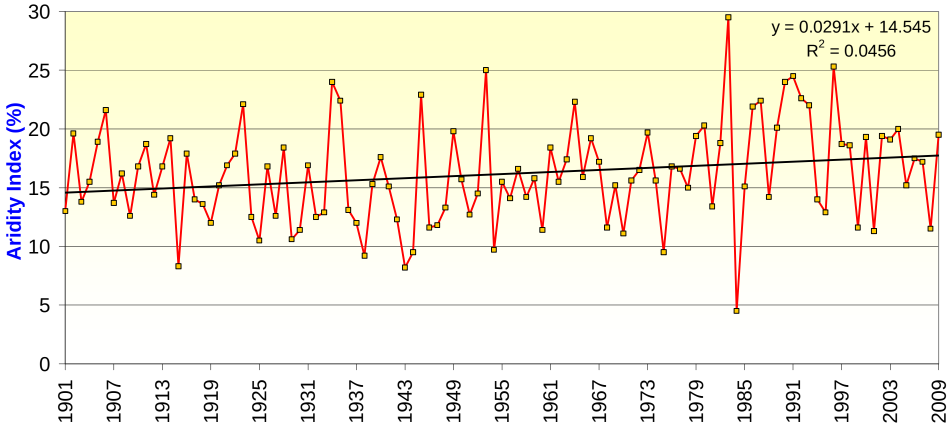


Fig. 6.9: March of aridity index (%) over Kerala from 1901 to 2009

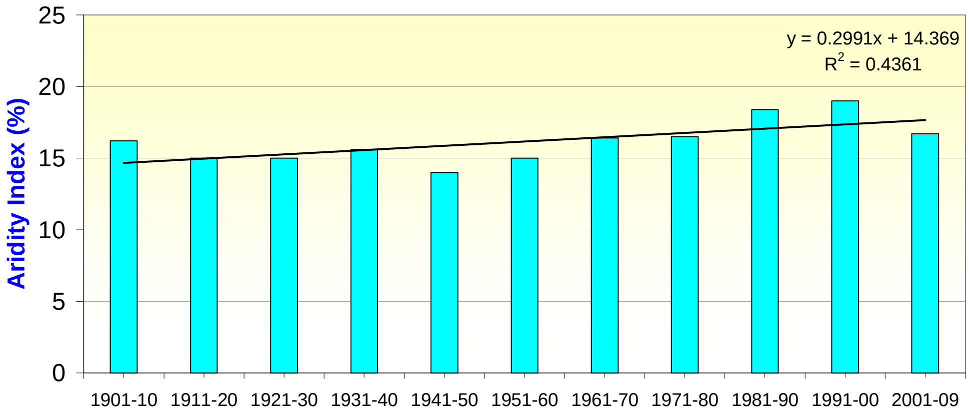


Fig. 6.10: Decade-wise aridity index from 1901 to 2009 over Kerala

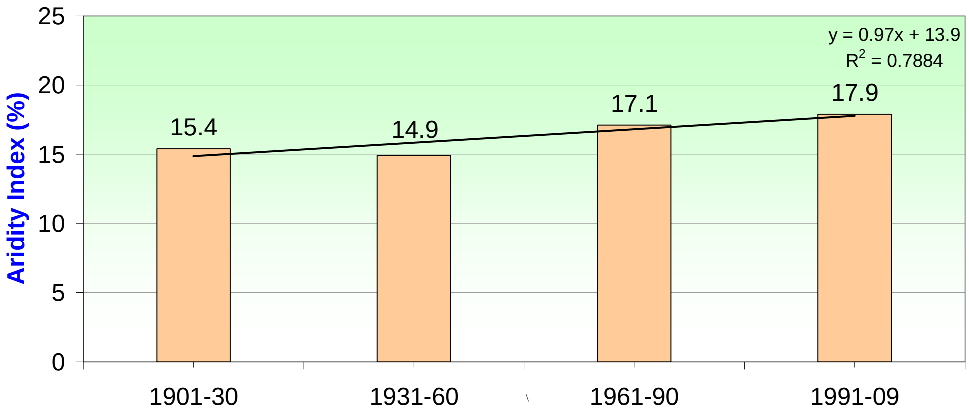


Fig. 6.11: Tri-decadal aridity index from 1901 to 2009 over Kerala

To derive climatological droughts, the aridity index was taken into account. The departure of aridity index from the median was considered for demarcating the intensity of droughts over Kerala. It indicated that the intensity of drought was increasing in recent decades of 1981-90 and 1991-2000 during which severe and disastrous droughts were noticed (Fig.6.12).

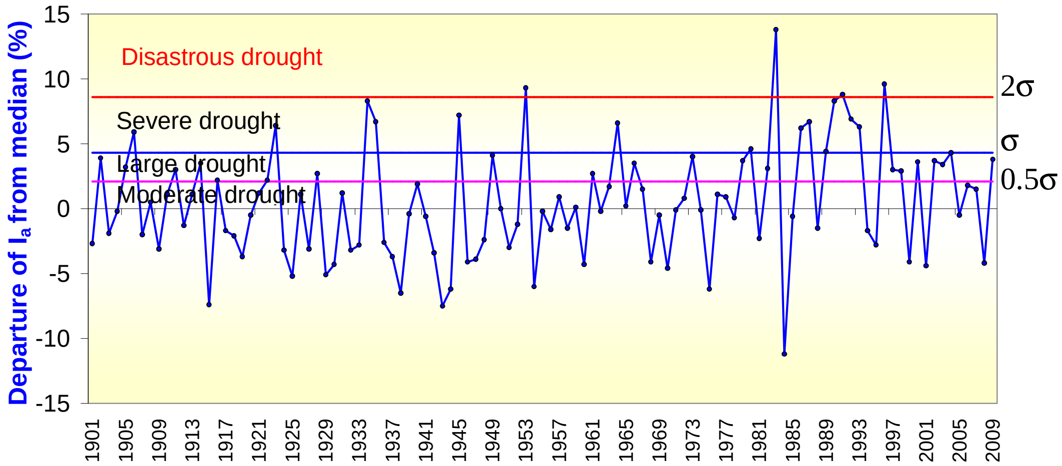


Fig. 6.12: Departure of Aridity index from the median from 1901 to 2009

The State of Kerala experienced 53 drought years out of 109 (1901-2009), of which seventeen were moderate, nineteen were large, thirteen were severe and four were disastrous droughts. The decade 1991-00 experienced more number of droughts (seven), followed by six each in 1961-70, 1971-80, 1981-90 and 2001-09 (Table 6.7).

Table 6.7: Occurrence and intensity of climatological droughts in Kerala from 1901 to 2009

Decade	Intensity of drought					Occurrence of drought (%)
	Moderate	Large	Severe	Disastrous	Total	
1901-10	2	2	1	0	5	50
1911-20	2	2	0	0	4	40
1921-30	2	2	1	0	5	50
1931-40	2	0	2	0	4	40
1941-50	0	1	1	0	2	20
1951-60	1	0	0	1	2	20
1961-70	3	2	1	0	6	60
1971-80	3	2	1	0	6	60
1981-90	0	1	4	1	6	60
1991-00	0	3	2	2	7	70
2001-09	2	4	0	0	6	66.7
Total	17	19	13	4	53	
Drought Intensity (%)	32.1	35.9	24.5	7.5		

There was a gradual decline in number of droughts years from 1901-10 (five) to 1951-60 (two) while increase from 1961-70 to 1991-2000. However, the intensity of drought was high in the decade 1981-90 in the form of severe and disastrous droughts. Over all, the percentage occurrence of large droughts was more (35.9%) across the State, followed by moderate (32.1%) and severe (24.5%). Only four years fell (7.5 per cent only) under the category of disastrous droughts.

6.4 CLIMATIC SHIFTS OVER KERALA

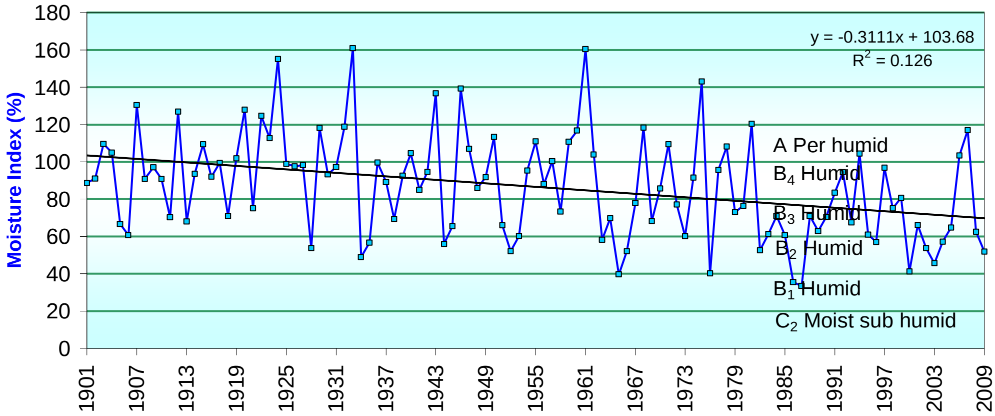
Kerala State falls under the climate type of "B_4 to A per humid" climate type in 29 years, indicated 26.6 per cent of the years on wetter side. In contrast, the State had shifted from B_4 to B_3, B_4 to B_2 and B_4 to B_1 in thirty (27.5%), sixteen (14.7%) and two (1.8%) years respectively, indicating drier side in 44% of the years. Only four years fell under the per humid (A) since last 29 years (Table 6.8). The moisture index was in decreasing trend (33.9%) from 1901 to 2009, indicating that the climate shifted from B_4 - humid to B_3, B_2 and B_1 humid in recent decades (Fig.6.13). The decreasing trend (1901-2009) was significant at 0.01 level. The climate shift towards drier side was more in the decade 1981-90 as only one year recorded per humid climate (A) while nine years between B_3 and B_1 of drier side. However, 1981-90 was a typical one as only one year was seen on wet side (per humid).

The decadal average of moisture index was low (63.9%) during 1981-90, followed by 2001-09 (69.1.4%), 1991- 00 (76.2 %) and 83.4% in 1961-70 while the moisture index was maximum (102.7%) during 1921-30, followed by 1941-50 (97.5%) and 96.0% in 1911-20 (Fig.6.14). The decadal moisture index also showed a decreasing trend of 3.1 % per decade. In terms of increase in temperature, dryness and intensity of drought, the decade 1981-90 can be considered as the warmest and driest decade during the study period. As a whole, the dryness was more evident since 1981 onwards if the decadal change is taken into account.

Table 6.8: Climatic shifts over Kerala from 1901 to 2009

Decade	Climatic type					
	B_1	B_2	B_3	B_4	A	Total
1901-1910	0	0	2	5	3	10
1911-1920	0	0	3	3	4	10
1921-1930	0	1	1	4	4	10
1931-1940	0	2	1	4	3	10
1941-1950	0	1	1	4	4	10
1951-1960	0	1	3	2	4	10
1961-1970	0	3	3	1	3	10
1971-1980	0	1	4	2	3	10
1981-1990	2	1	6	0	1	10
1991-2000	0	2	3	4	1	10
2001-2009	0	4	3	0	2	9
Total	2	16	30	29	32	109
Climatic shifts (%)	1.8	14.7	27.5	26.6	29.4	

The tri-decadal moisture index was also declining (0.97% per 30 years) from 1901 to 2009. It was high (97.3%) during 1901-30, followed by 1931-60 (92.9%) and 1961- 90 (78.3 %) while the moisture index was low (72.7%) during 1991-09 (Fig.6.15). A gradual decline in moisture index is a sign of climate change in Kerala and the State was moving from wetness to dryness with in B- type of climates. From the above studies, it is clear that the global warming and climate change is real over Kerala and climate shifted from B_4 to B_3 humid type. It is more evident since 1961 onwards on tri-decadal basis.



\ Fig. 6.13: Moisture index from 1901 to 2009 over Kerala

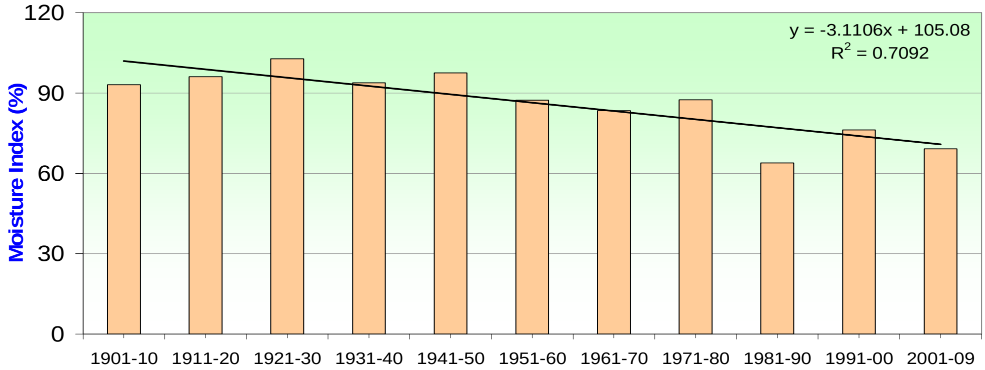


Fig. 6.14: Decade-wise moisture index from 1901 to 2009 over Kerala

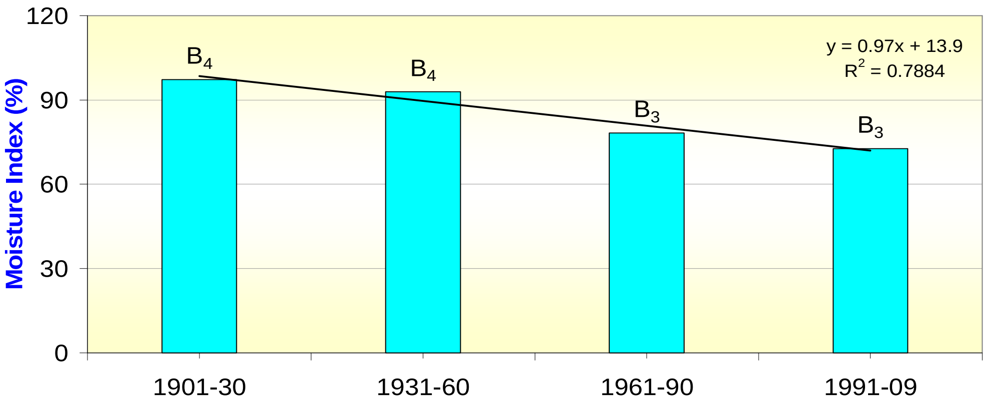


Fig. 6.15: Tri-decadal moisture index from 1901 to 2009 over Kerala

6.5 CLIMATE CHANGE AND COCONUT PRODUCTIVITY IN KERALA

Climate and climatic change in recent decades become the subject of world-wide discussion. Even high technology was no match in years of drought/ floods during which abnormal weather variations were noticed. For example, the recent drought in kharif 1987, 2002 and 2009 due to monsoon break resulted in low *kharif* Indian foodgrains production despite different crop strategies coupled with agrotechniques were adapted to mitigate the effect of prolonged dry spell. Similar was the case in kharif 1993 in Rajasthan as *Kharif* crops failed totally due to monsoon failure. In Kerala also, a similar situation was seen in summer 1982-83 which experienced the unprecedented drought due to insignificant rains from 4^{th} November 1982 to 13^{th} June 1983. This led to a drastic decline in coconut crop production in the subsequent year. The decline in coconut yield due to drought was about thirty per cent in the subsequent year even under well managed coconut gardens (Rao, 1986). In the humid tropics like Kerala, where the monsoon rainfall is stable and dependable, the intra/inter seasonal fluctuations in rainfall are not uncommon which lead to floods/ droughts. Events of this kind repeated frequently in recent years in Kerala from the erratic behaviour of rainfall during southwest and northeast monsoons. It appears in plantation growers` mind that whether the above events will frequently occur in Kerala and lead to decline in plantation crop production.

6.5.1 Climate change

The annual maximum temperature across the State was increasing at the rate of 0.4°C for tri-decade, and it is likely to be 32.2°C, 32.6°C, 33.0°C and 33.3°C by 2020, 2050, 2080 and 2100, respectively for the State of Kerala as against the average maximum temperature of 31.8°C under the present condition (Fig.6.16).

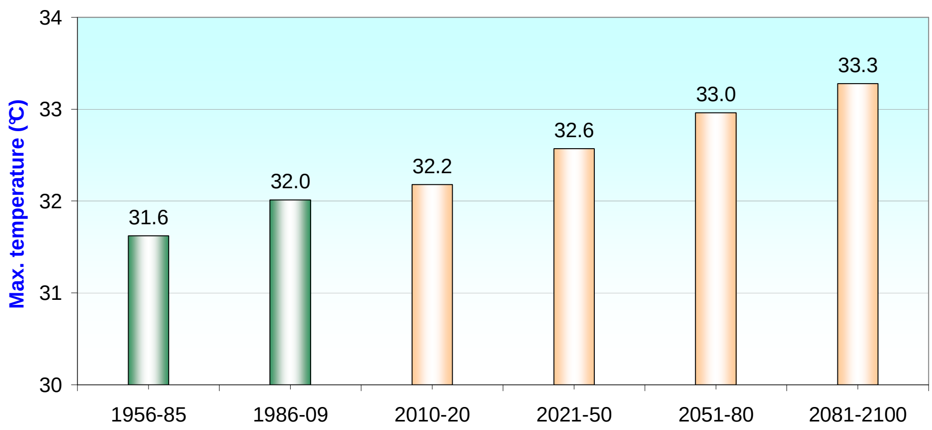


Fig. 6.16: Projected annual maximum temperature over Kerala

At the current rate of increase in maximum temperature, the increase by 2050 and 2080 is likely to vary between 1 and 1.3°C, respectively.

At present, the annual minimum temperature across the State was increasing at the rate of 0.1°C for tri-decade. The minimum temperature is likely to be 23.45°C, 23.55°C, 23.65°C and 23.73°C by 2020, 2050, 2080 and 2100, respectively for the Sate of Kerala (Fig.6.17). At this rate, the increase in minimum temperature is likely to be between 0.25 and 0.33 by 2050 and 2100, respectively.

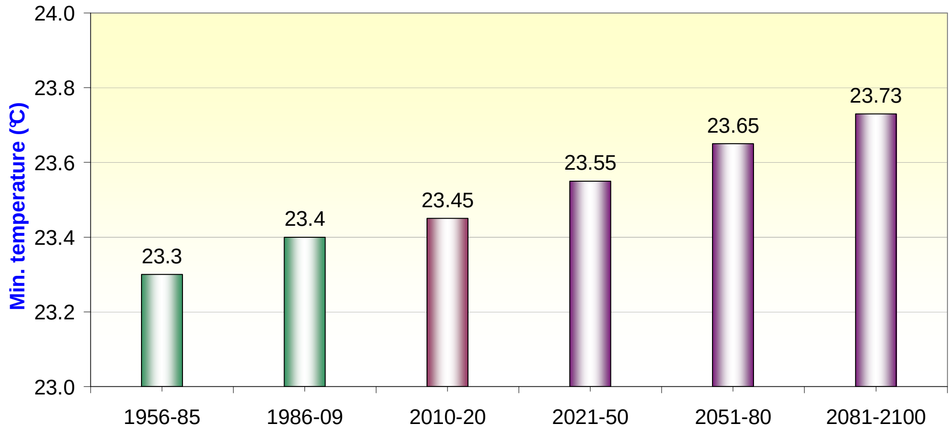


Fig. 6.17: Projected annual minimum temperature over Kerala

The annual mean temperature across the State was increasing at the rate of 0.3°C for tri-decade, the mean temperature is likely to be 27.8°C, 28.1°C, 28.4°C and 28.6°C by 2020, 2050, 2080 and 2100 AD, respectively for the State of Kerala (Fig.6.18).

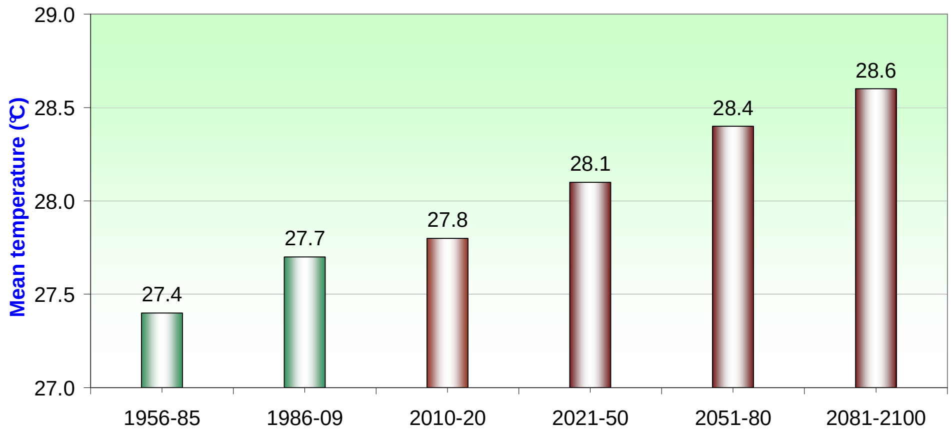


Fig. 6.18: Projected annual mean temperature over Kerala

Increase in the mean temperature is likely to be 0.4 and 0.7 and 0.9°C by 2020, 2080 and 2100AD, respectively. From the above, it is understood that the projected increase in maximum temperature is likely to be 0.2 to 1.3°C by 2100 AD while it was between 0.05 to 0.33 °C in the case of minimum temperature (Fig.6.19).

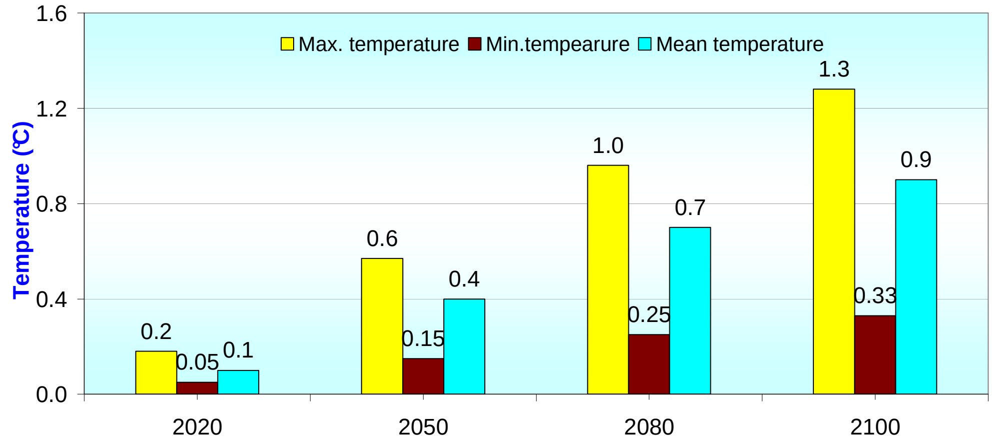


Fig. 6.19: Projected increase in maximum, minimum and mean temperature by 2020, 2050, 2080 and 2100 since 2010

The mean surface air temperature is likely to be between 0.1 to 0.9°C by 2100AD. It revealed that the rate of increase is likely to be more in the case of maximum temperature when compared to that of minimum temperature. As the maximum and minimum temperatures were in increasing trend, hot summers are likely in ensuing decades. Of course, the rate of increase in temperature during ensuing decades may vary depending upon the emission of greenhouse gases, in particular the emission of CO_2 as it accounts up to 70-75% of increase in atmospheric temperature. The rainfall analysis revealed that a significant increase in post monsoon rainfall over the State of Kerala while the southwest monsoon rainfall decreasing but it was not significant. Rainfall during winter and summer seasons showed insignificant increasing trend. Unlike temperature trends, rainfall trends are not uniform as seen on season - wise. Therefore, the rainfall projections were not worked out. However, rainfall distribution is likely to be erratic with decline in monsoon rainfall while increase in post monsoon rainfall as evident currently.

6.5.2 Trends in coconut area, production and productivity in Kerala

The trend in coconut area from 1951-60 to 2008-09 was steadily increasing and the percentage increase over the period was 92% (Fig.6.20). It is obvious that the coconut production since last six decades followed the similar trend of coconut area. In the case of coconut productivity, there was a sharp decline from 1951-60 (6578 nuts/ha) to 1981-90 (4693/ha) and thereafter increase was noticed since last two decades. However, the coconut productivity could not reach to the level of 1950s (6578 nuts/ha).

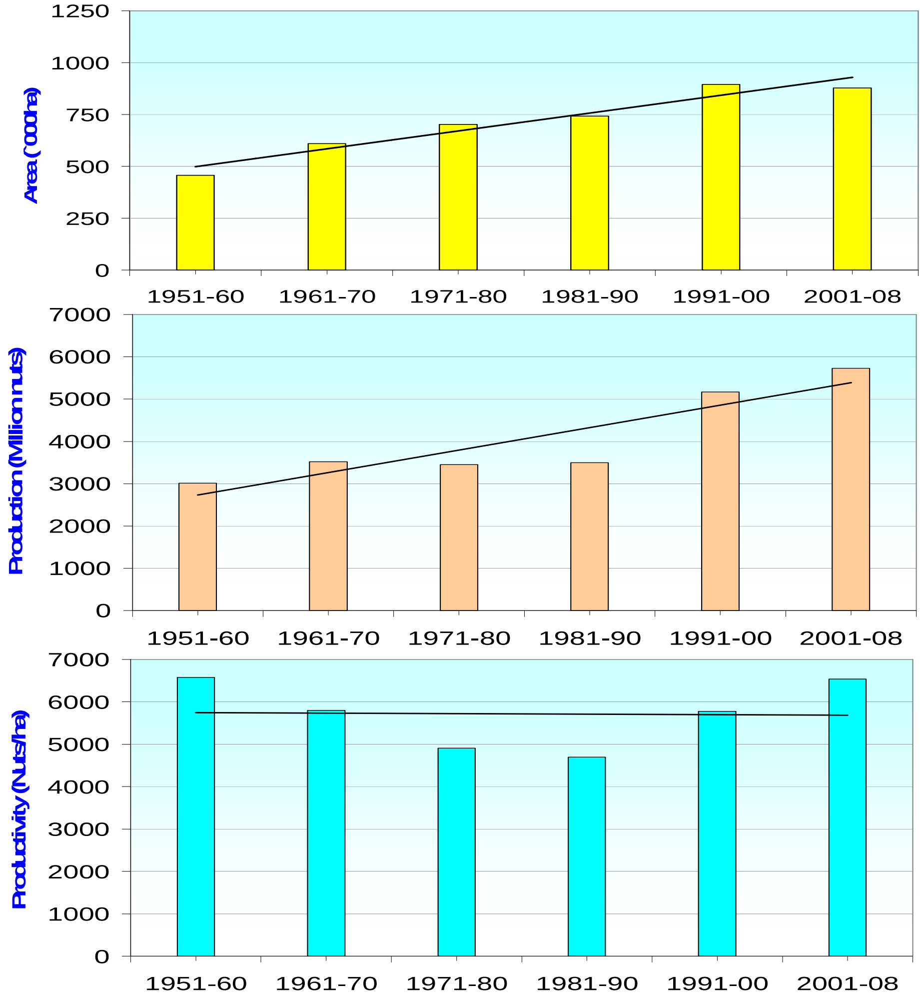


Fig. 6.20: Trend in decadal area, production and productivity of coconut over Kerala

The percentage decadal departure in terms of area, production and productivity in coconut clearly brought out the negative trends in the decades 1961-70 and 1981-90 (Fig.

6.21). The negative trend in coconut productivity was much more (17.9%) in the decade 1981-90.

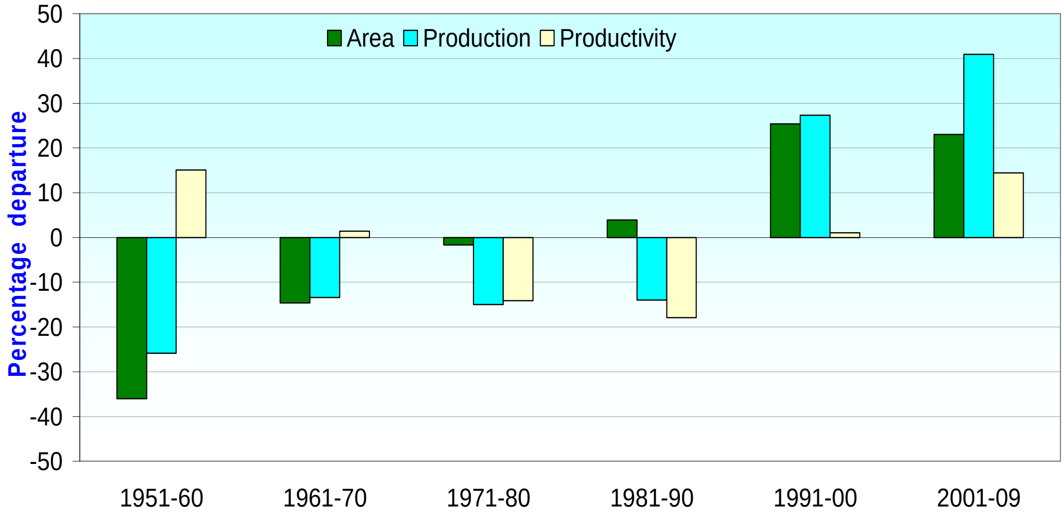


Fig. 6.21: Percentage decadal departure of area, production and productivity from the mean

6.5.3 Climate variability and coconut productivity

The decade 1981-90 in Kerala was the warmest decade in terms of high temperature and the driest decade in terms of intensity of summer drought. Both together adversely affected the coconut productivity. It is one of the reasons, why, coconut productivity was low in the decade 1981-90. The coconut productivity was the least in 1983-84 (3814 nuts/ha), followed by 1987-88 (4315 nuts/ha) and 1986 - 87 (4494 nuts/ha) as against the normal productivity of 5675 nuts/ha. The decline in coconut productivity of Kerala was maximum during 1983-84 (19.2%), followed by 1986-87 (6.2%) and 4.0% in 1987-88 when compared to the respective previous year. Interestingly, all the above three low coconut productivity years fell in the decade 1981-90 (*see Fig 6.23*). In addition, replanting of coconut was taken up during 1960s and 1970s due to senile palms and spread of root wilt of coconut in southern districts of Kerala. However, the decline in coconut productivity in the decade 1981- 90 was predominately due to the occurrence of summer droughts. Such was the case in the year 2002-03 during which the coconut productivity was less by 3.6% (5895 nuts/ha) in the recent decade. The interannual variation in coconut production since last one decade could be attributed due to weather aberrations in terms of prolonged rainy season like 2007 and 2010, continuous decline in monsoon rainfall from 1999 to 2005 resulted to scarce water resources during summer, heavy heat load during summer in 2004, 2009 and 2010 due to high maximum temperature and severe attack of coconut mite in addition to low market price. As a result of continuous decline in rainfall there was a hydrological drought during summer 2004 and the coconut production was adversely affected. The low coconut market price from 2007 to 2009 led the farmers to neglect the coconut gardens. As a result, the coconut production during 2010 was very low in the State of Kerala. It was one of the reasons for price hike in the last quarter of 2010 in the case of coconut. This situation is likely to continue in 2011 too. As per the latest reports, it indicated that the import of coconut oil was the least in 2009-10. The percentage decline in coconut oil import was 74.8% in 2009-10 when compared to that of 2008-09. This was another factor for increase in coconut price during 2010-11.

6.5.4 Climate change impact on coconut productivity

The coconut productivity on tri - decadal basis was high (5762 nuts/ha) during 1951-80 when compared to that of 1981-09 (5670nuts/ha). The percentage decline was 1.6% in 1981-09 when compared to that of 1951-80. It could be attributed to climate change as there was a decline in coconut productivity from the previous tri-decade (1951-80) to current tri - decade 1981-09. There was a distinct difference in rainfall distribution, aridity index, number of summer droughts, moisture index and temperature from 1951-80 to 1981-09. Increase in temperature, aridity index, number of severe summer droughts and decline in rainfall and moisture index were the major factors for a marginal decline or stagnation in coconut productivity over a period of time. It can be clear signal of decline in coconut productivity due to global warming and climate change (Fig. 6.22 and Fig.6.23). Therefore, there is a threat to coconut productivity in the ensuing decades due to climate variability and climate change (Fig.6.24). In view of the above, there is an urgent need for pro-active measures as a part of climate change adaptation to sustain coconut productivity in the State of Kerala, having a lion share in coconut productivity of the country.

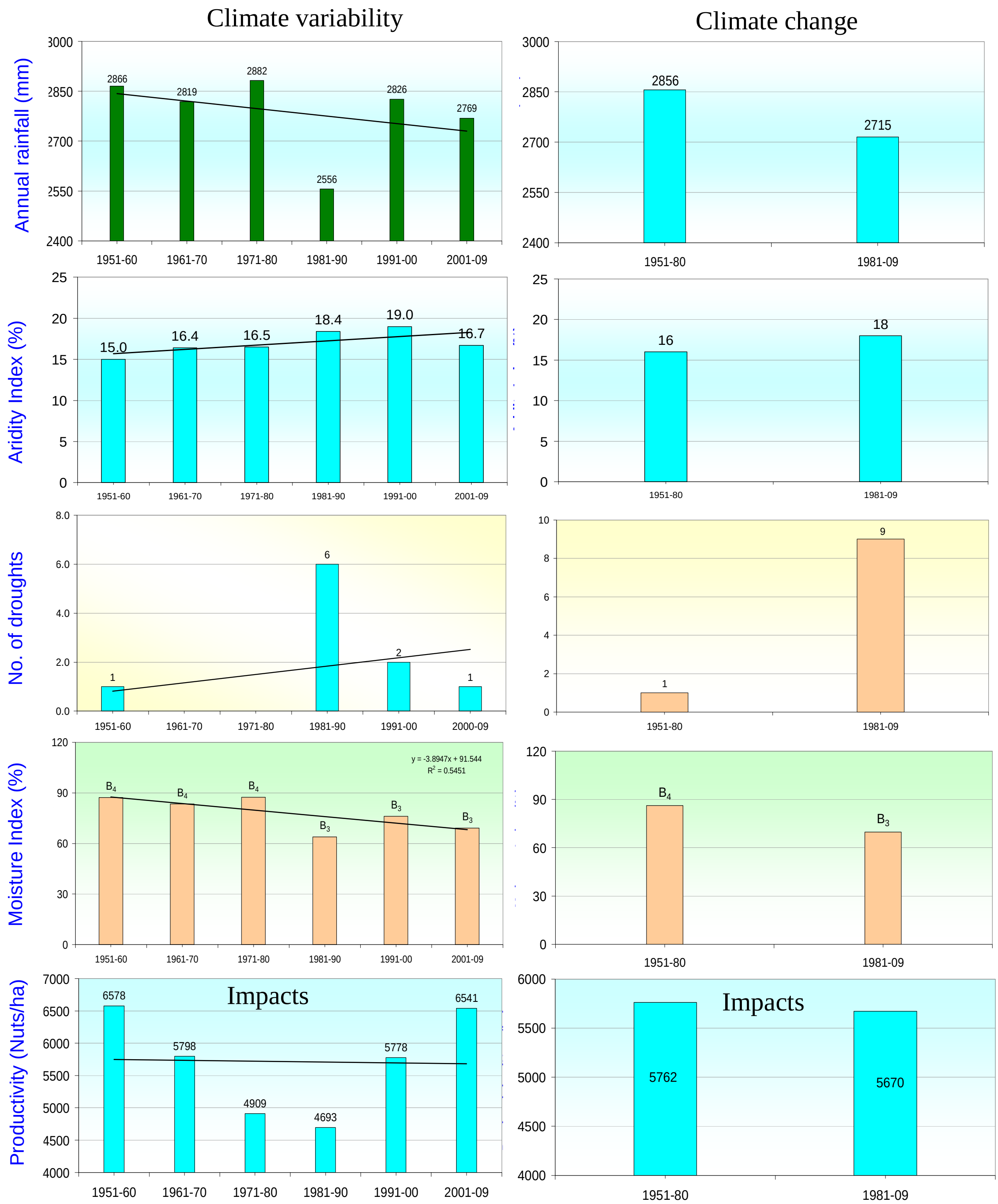


Fig. 6.22: Decadal and tri-decadal annual rainfall, aridity index, number of summer droughts, moisture index and productivity of coconut

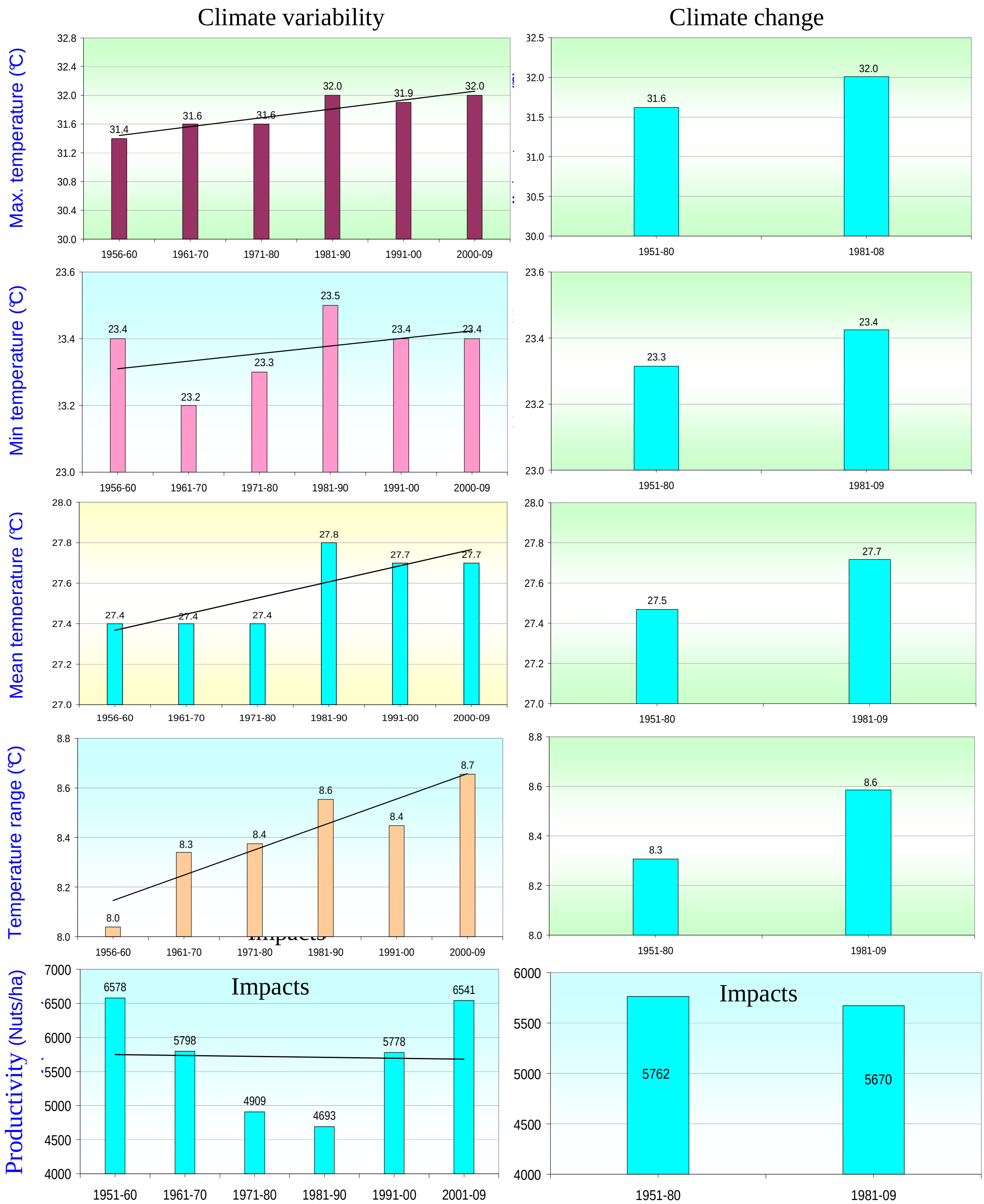


Fig. 6.23: Decadal and tri-decadal maximum, minimum, mean temperature, temperature range and productivity of coconut

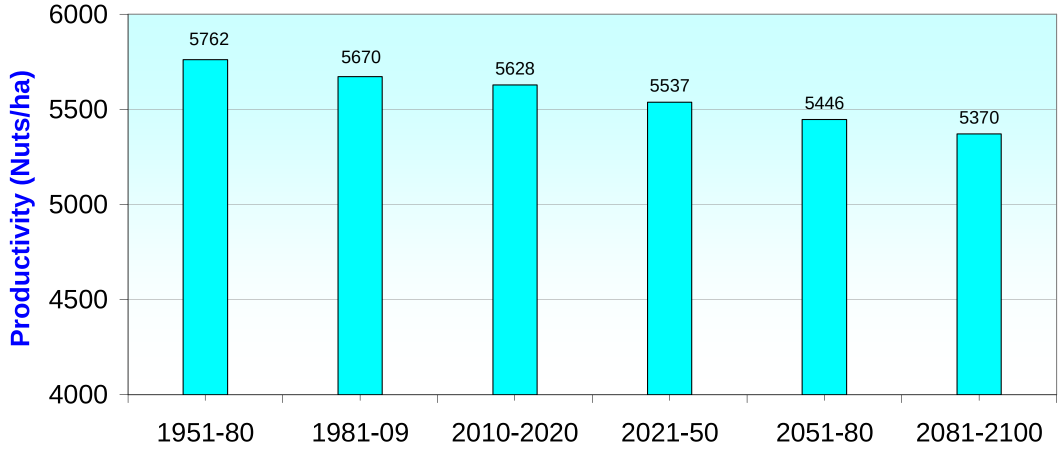


Fig. 6.24: Projected coconut productivity by 2020, 2030, 2050, 2080 and 2100

The Impact of climate change on coconut production was also assessed by Kumar and Aggarwal (2009) for 13 agro-climatic zones represented by 16 centres using validated Info Crop-Coconut simulation model. The model output on temperature and rainfall projections as simulated by Had CM3 model for the years 2020, 2050 and 2080 for 3 scenarios viz., A2a, B2a and A1F wherein the atmospheric concentrations would reach by 715, 562 and 1150 ppm and the corresponding increase in global temperatures would be about 3.3°, 2.3° and 4°C, respectively by the end of the century. However, the recent model output indicates that the global warming is likely to be below 3°C by 2100 AD and through mitigation strategies already ongoing across the world, it is likely to be between 2 and 2.5°C. Since the projected CO_2 levels are abnormally high, it is obvious that the temperature rise projected also will be high. Even at high temperature projections, the authors indicate that the coconut productivity on all India basis is likely to go up by up to 4% during 2020, up to 10% in 2050 and up to 20% in 2080 over current yields due to climate change. Along the west coast, yields are projected to increase by up to 10% in 2020, up to 16% in 2050 and up to 39% by 2080 while in the East coast yields are projected to decline by up to 2% in 2020, 8% in 2050 and 31% in 2080 over current yields. Yields are projected to go up in Kerala, Maharastra and parts of Tamil Nadu and

Karnataka while they are projected to decline in Andhra Pradesh, Orissa, Gujarat and parts of Tamil Nadu and Karnataka. It reveals that coconut productivity across the State of Kerala is likely to increase due to global warming and climate change. However, the model results cannot be taken into account on real time basis as the global warming is likely to increase the frequency of occurrence of floods and droughts, which affect coconut production adversely as seen in the past in the State of Kerala. Moreover, any increase in temperature during the second phase of nut development is likely to influence the nut size and thereby the copra outturn and oil content. The second phase of nut development is more sensitive to high temperature. In addition, the inputs like projected CO_2 levels used in the model may also not be realistic. Therefore, the coconut productivity is unlikely to decline under the projected climate change scenario as the occurrence of floods and droughts is likely to affect the crop adversely and their frequency is likely to increase under the projected climate change scenario.

There was a decline of 54.2% in summer mean rainfall from December to May while increase in mean temperature was 0.8°C during the drought years in 1983, 1986 and 1987 in the warmest decade of 1981-90. The increase in maximum temperature varied between 0.5 and 1.3°C while minimum temperature between 0.2 and 0.9°C during the above years. The maximum temperature varied between 34.4 and 35.2°C as against the mean maximum of 33.9°C (Table 6.9). The increase in annual maximum temperature varied between 0.4 and 1.0°C while the minimum between 0.3 and 0.7°C during 1983, 1986 and 1987. The increase in average temperature varied between 0.3 and 0.5°C. The decline rainfall in summer leads to moderate to heavy soil moisture stress depending upon its distribution. In such a situation any increase in temperature may adversely affect the coconut yield under the rainfed conditions. It reveals that decline in rainfall together with increase in temperature for longer duration from December to May will lead to decline in coconut yield.

Table 6.9: Temperature and rainfall during the low coconut productivity years in the warmest decade of 1981-90

Season	Year	Temperature (°C)				Increase in temperature (°C)			
		Max	Min	Mean	Range	Max	Min	Mean	Range
Annual	1983	32.4	24.0	28.2	8.4	0.6	0.6	0.6	0.0
	1986	32.2	23.6	27.9	8.5	0.4	0.2	0.3	0.1
	1987	32.8	23.8	28.3	8.9	1.0	0.4	0.7	0.5
	Mean	31.8	23.4	27.6	8.4	0.7	0.4	0.5	0.2
Summer	1983	35.1	25.6	30.3	9.4	1.2	0.9	1.0	0.2
	1986	34.4	25.3	29.8	9.2	0.5	0.6	0.5	0.0
	1987	35.2	24.9	30.1	10.3	1.3	0.2	0.8	1.1
	Mean	33.9	24.7	29.3	9.2	1.0	0.6	0.8	0.4
		Rainfall (mm)				Percentage decline			
Dec-May	1983	112.6				-75.6			
	1986	298.1				-35.5			
	1987	224.2				-51.5			
	Total	462.4				54.2			

Therefore, warming Kerala adversely affect the coconut yield under the projected climate change scenario. Despite advanced technologies, varieties introduced, increase in coconut area under irrigation during summer with better crop management and protection measures, the coconut productivity could not be increased during the current tri-decade of 1981-2009 when compared to that of previous tri - decade of 1951-1980. In fact, there was a marginal decline in coconut productivity. It could be attributed to climate change as evident in terms of increase in temperature, aridity index, number of severe summer droughts and decline in rainfall and moisture index during the warmest and driest decade of 1981-90 in Kerala. Moreover, any increase in temperature is likely to lead to more water demand and the coconut crop is likely to be under soil moisture stress in lean months under rainfed condition with scarce water resources as majority of coconut gardens in Kerala are grown under rainfed conditions. In view of the above, the Info Crop-Coconut simulation model taken up in the case of coconut productivity projections need to be modified and tested further.

6.5.5 Climate variability and coconut prices

Global warming and climate change may lead to occurrence of floods and droughts and cold and heat weaves across the World. It was more so in recent decades. The global foodgrain production was adversely affected due to occurrence of flood and droughts and heat and cold waves. As a result of low foodgrains the world over, the food price escalation is alarming since 2007/2008 onwards. For the first time, it was felt that the global warming and climate change may indirectly lead to food price escalation due to low production of foodgrains across the World. Therefore, weather aberrations may indirectly lead to increase in food price globally in ensuing decades as their frequency is likely to increase. Of course, the food price fluctuation is a complex one and depends on several internal and external factors in addition to weather aberrations. In coconut also, such trends were seen in price fluctuations in Kerala, which is a major coconut producing state in the country. Many of the researchers, while studying the price behaviour of coconut, copra and coconut oil, observed seasonality in price (Babu and Sebastian 1996), but it was also observed that much of variation was due to irregular components (Haridas and Chandran, 1997). Gadhavi *et al*., (2001) also studied the price behavior of coconut in Saurashtra region of Gujarat State. A steep increase in coconut price was 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/- per quintal of copra. Under the open auction sale, on an average Rs. 3.07/- per coconut was obtained at the Regional Agricultural Research Station, Pilicode in 1984 as against Rs 1.70/- per nut in 1983 (Table 6.10). Such trend was seen in lean crop years due to adverse affect of weather vagaries. Again, the price hike in coconut was noticed from 1991 to 1993, 1996 to 1999 and from 2002 to 2006. A steep increase in coconut price was again noticed since October 2010 onwards due low coconut production within the State of Kerala and neighboring coconut producing states.

Table 6.10: Climate Variability and coconut prices (RARS, Pilicode)

Year	Price of coconut in Indian Rupees			Year	Price of coconut in Indian Rupees		
	Highest	Lowest	Average		Highest	Lowest	Average
1979	1.10 (Mar)	0.99 (July)	1.03	1995	3.45 (Dec)	2.75 (Jan)	3.00
1980	1.64 (Oct)	1.46 (Dec)	1.50	1996	5.82 (Dec)	3.00 (Aug)	3.86
1981	1.65 (May)	1.06 (Oct)	1.31	1997	5.67 (Jan)	4.21 (Sep)	4.82
1982	1.40 (Dec)	1.00 (Jan)	1.18	1998	4.45 (April)	3.77 (Sep)	4.00
1983	2.10 (Sep)	1.30 (May)	1.70	1999	5.70 (July)	3.75 (Jan)	4.91
1984	3.50 (June)	2.10 (Jan)	3.07	2000	4.56 (Jan)	2.4 (Oct)	3.22
1985	2.27 (Feb)	1.30 (Nov)	1.69	2001	3.60 (Dec)	2.46 (Feb)	3.00
1986	2.25 (Nov)	1.37 (Feb)	1.89	2002	4.62 (Dec)	4.00 (April)	4.37
1987	2.80 (Dec)	2.30 (Jan)	2.56	2003	5.62 (Oct)	4.30 (May)	4.93
1988	3.20 (Dec)	2.35 (July)	2.77	2004	5.90 (Aug)	5.26 (May)	5.58
1989	2.15 (May)	1.72 (Oct)	1.93	2005	5.50 (April)	3.81 (Nov)	4.66
1990	3.00 (Dec)	1.78 (Jan)	2.26	2006	5. 00 (Feb)	3.13 (July)	4.07
1991	3.80 (Feb)	1.10 (May)	3.15	2007	3.70 (Dec)	3.33 (Sept)	3.52
1992	4.20 (Mar)	3.85 (May)	3.98	2008	4.63 (July)	3.73 (Jan)	4.18
1993	4.51 (Jan)	3.20 (July)	3.90	2009	4.65 (Feb)	3.01 (Oct)	3.83
1994	3.71 (Dec)	2.51 (Sep)	2.77	2010	6.50 (Dec)	3.30 (Jan)	4.90

The coconut farmers get Rs 6-10/- per nut depending upon the nut size. Consumer is paying Rs 8-12/- per nut as per the coconut price prevailing in the market during January 2011. One of the factors attributed to low production in 2010 was due to negligence of coconut gardens without any crop management and improvement practices due to very low coconut price offered to coconut farmers in addition to the adverse affect of weather aberrations in the State of Kerala. In addition, coconut price in Kerala may depends on several factors viz., import export policy, total coconut production outside Kerala, less edible oil consumption coconut oil use in the industries as several substitutes are used in place of coconut oil. Import of palmolene oil may be one of the major contribution factors in declining oil price. The ever highest price of coconut was offered in December 2010 (Rs. 6.50/nut), followed by 1999 July (Rs. 5.70/nut) and January 1997 (Rs. 5.67/nut) while the lowest price noticed in July 1979 (Rs 0.99/nut), followed by 1982 January (Rs.1.00/nut) and 1981 October (Rs.1.06/nut). At present, the coconut price in

Kerala is very high (more than Rs 8/- per nut) in the open market and coconut growers get reasonably good price for his farm produce (Fig.2.25). The price per coconut revolved only between Rs.3/- and 4/- from 2007 to the third quarter of 2010. Another reason for price hike is that the oil-palm yields in Indonesia and Malaysia have shrunk this year because of dryness caused by El Nino and heavy rain brought on by La Nina. The import of coconut oil was also very low. The percentage decline in import of coconut oil in 2009-10 was 74.9% when compared to that of 2008-09.

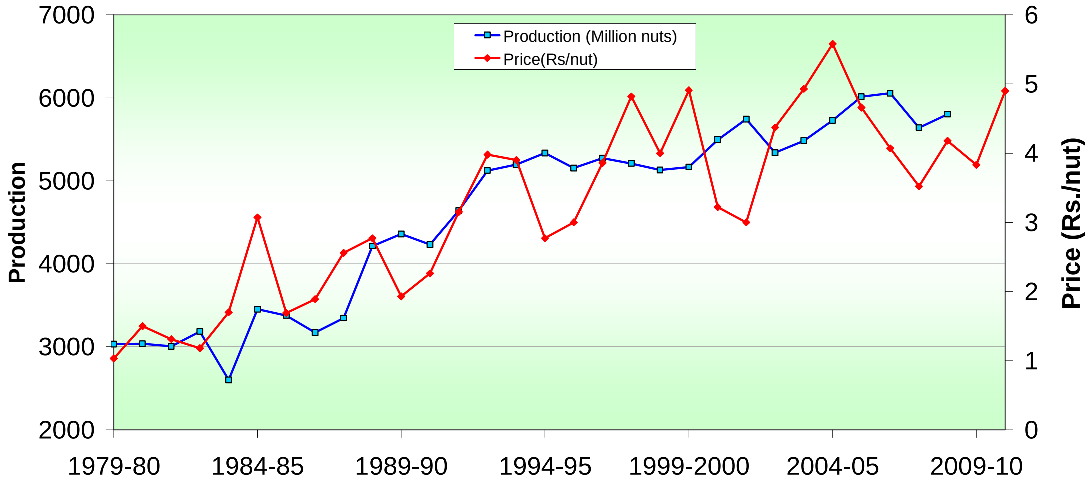


Fig. 6.25: Coconut production and nut prices over Kerala

With all above the factors which influence the hike in coconut price, there is a strong linkage between the local coconut production and price as seen in the case of low coconut production during weather abnormalities like severe summer droughts in the State of Kerala. It indicates that pro - active measures in terms of EXIM policies and local regulations at the State level are the need of the hour against price hike in the event of weather abnormalities which influence the coconut production adversely.

Chapter VII

Crop yield forecasting of coconut

7.1 EFFECT OF WEATHER VARIABLES ON COCONUT YIELD

7.1.1 Temperature

The maximum temperature during May showed significant negative influence on coconut productivity during the current year, one year, two year, three year lag period. April maximum temperature had significant negative influence on productivity during the current year and two year lag period. The maximum temperature during October had significant negative influence on productivity during two year and three year lag period (Table 7.1). Rest of the months had no significant influence on coconut productivity.

Table 7.1: Correlation between Maximum temperature and coconut productivity

Month/season	Current year	Lag period		
		One year	Two year	Three year
January	-0.004	0.059	0.066	0.196
February	-0.065	-0.040	-0.022	0.098
March	-0.222	-0.052	-0.216	0.038
April	-0.291*	-0.201	-0.271*	-0.202
May	-0.457**	-0.418**	-0.365**	-0.270*
June	-0.076	0.008	-0.134	-0.071
July	-0.161	-0.181	-0.235	-0.147
August	0.056	0.171	0.102	0.153
September	-0.242	-0.204	-0.154	-0.124
October	-0.226	-0.185	-0.319*	-0.270*
November	-0.064	-0.089	0.005	-0.033
December	-0.189	-0.117	-0.155	-0.155
Annual	-0.302*	-0.289*	-0.161	-0.030
Summer	-0.400**	-0.392**	-0.232	-0.210
Southwest monsoon	-0.126	-0.153	-0.077	0.050
Post Monsoon	-0.230	-0.213	-0.199	-0.060
Winter	-0.088	-0.064	-0.055	0.110

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

The annual and summer maximum temperature showed significant negative influence on coconut productivity. The results indicated that high maximum temperature during the current year and one year prior to harvest had detrimental effect on productivity. It was found that when the summer maximum temperature crossed above the average value of 33.9°C, the coconut productivity was below (69.2% of years) average in the following year (Fig 7.1).

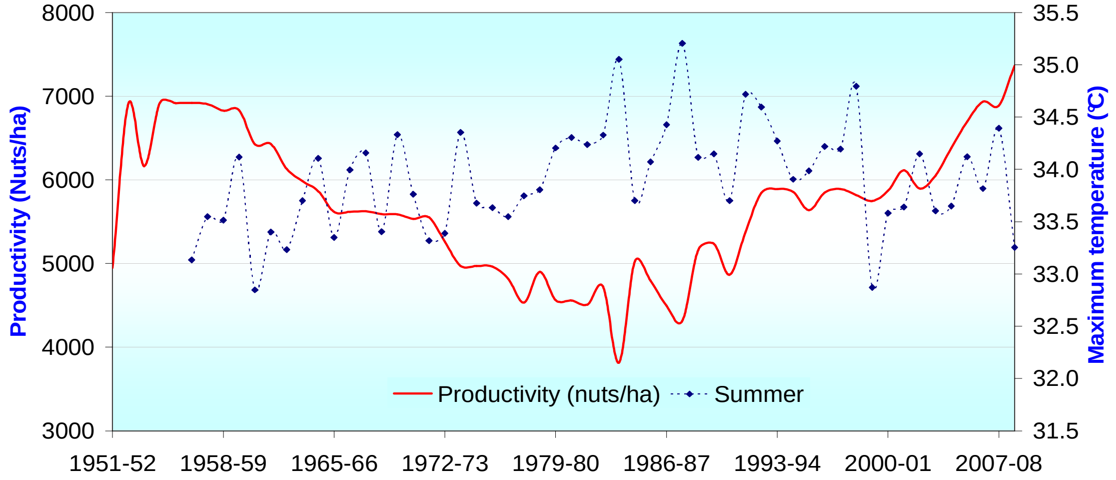


Fig.7.1: The effect of summer maximum temperature (one year lag) on coconut productivity

Non orthogonal analysis of the summer maximum temperature during one year lag period and coconut productivity indicated that 22.5% of variability is explained by summer maximum temperature. It was observed that when annual maximum temperature crossed above the average value of 31.8°C, the coconut productivity is below (48.2% of years) average in the following year (Fig. 7.2).

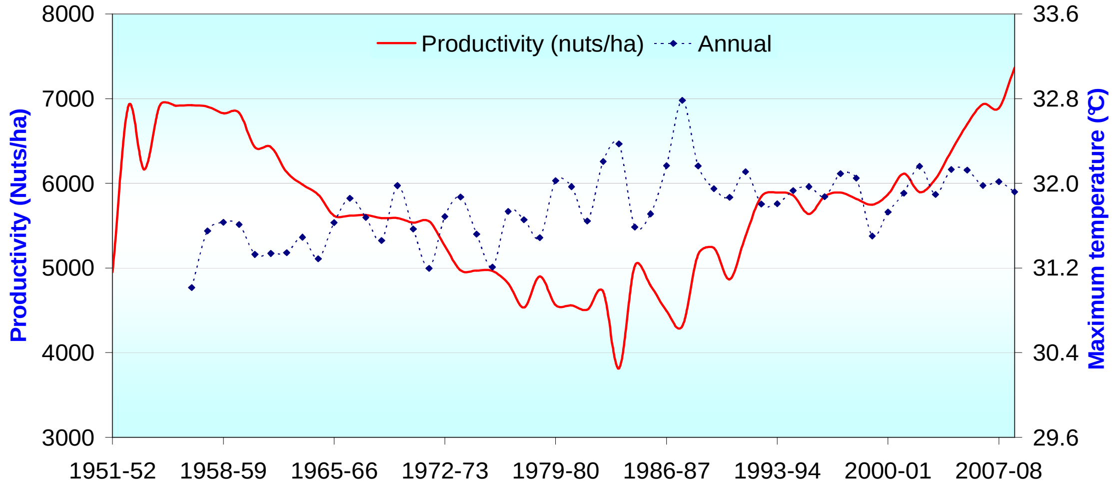


Fig. 7.2: The effect of annual maximum temperature (one year lag) on coconut productivity

The minimum temperature during May had significant negative influence on coconut productivity during current, one year and two year lag period (Table 7.2).

Table 7.2: Correlation between Minimum temperature and coconut productivity

Month/season	Current year	Lag period		
		One year	Two year	Three year
January	0.101	0.100	0.222	0.294*
February	0.081	0.006	0.155	0.155
March	-0.066	0.040	0.050	0.214
April	-0.203	-0.185	-0.207	-0.138
May	-0.368**	-0.329*	-0.284*	-0.183
June	0.045	0.159	-0.039	0.076
July	-0.047	-0.083	-0.159	-0.086
August	0.149	0.202	0.096	0.263*
September	-0.135	-0.086	-0.224	-0.041
October	-0.121	-0.014	-0.166	0.000
November	-0.004	0.009	-0.029	0.044
December	-0.116	-0.063	-0.186	-0.184
Annual	-0.053	-0.087	0.060	0.130
Summer	-0.234	-0.208	-0.066	-0.030
Southwest monsoon	0.050	-0.099	0.069	0.120
Post Monsoon	0.008	-0.103	0.026	0.130
Winter	0.048	-0.024	0.096	0.140

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

The minimum temperature during January and August had significant positive correlation on coconut productivity during three year lag period. Rest of the months and seasons had no significant influence on coconut productivity.

The mean temperature during May and April showed significant negative influence on coconut productivity during the current year, one year, two year, three year lag period (Table 7.3). The mean temperature during October had significant negative influence on coconut productivity during the two year lag period. Rest of the months had no significant influence on coconut productivity.

Table 7.3: Correlation between Mean temperature and coconut productivity

Month/season	Current year	Lag period		
		One year	Two year	Three year
January	0.069	0.095	0.183	0.288*
February	0.029	-0.016	0.107	0.164
March	-0.176	-0.010	-0.105	0.154
April	-0.273*	-0.211	-0.264*	-0.190
May	-0.439**	-0.400**	-0.348**	-0.246
June	-0.034	0.065	-0.105	-0.019
July	-0.127	-0.154	-0.221	-0.133
August	0.102	0.207	0.113	0.222
September	-0.229	-0.183	-0.194	-0.107
October	-0.211	-0.140	-0.296*	-0.196
November	-0.048	-0.058	-0.014	0.003
December	-0.187	-0.109	-0.222	-0.220
Annual	-0.216	-0.225	-0.070	0.050
Summer	-0.357**	-0.340**	-0.176	-0.140
Southwest monsoon	-0.068	-0.146	-0.026	0.080
Post Monsoon	-0.156	-0.196	-0.124	0.020
Winter	-0.012	-0.048	0.038	0.140

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

The summer average temperature showed significant negative influence on coconut productivity. The result indicated that high average temperature during the current year and one year prior harvest had negative effect on productivity. It was observed that when the average temperature crossed above the average value of 29.3° during the previous summer, the coconut productivity was below (73.9% of years) average in the following year (Fig.7.3).

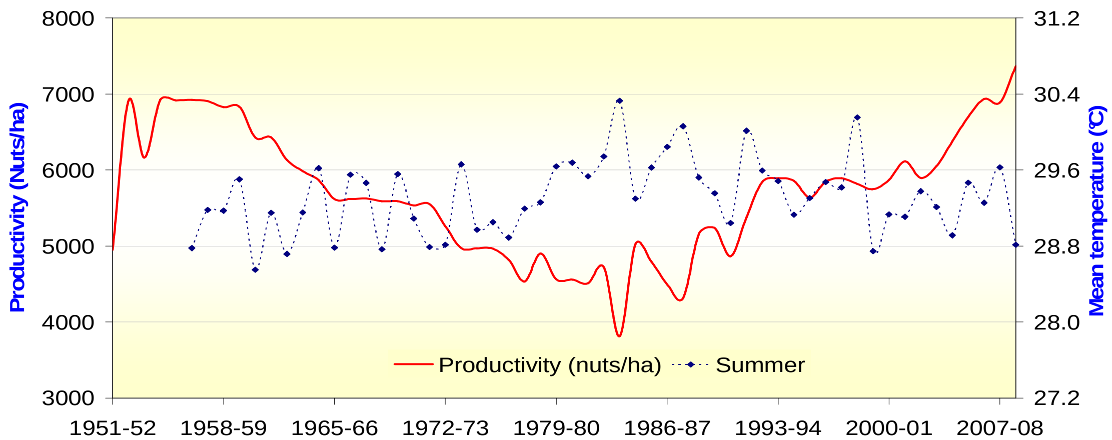


Fig.7.3: The effect of mean temperature (one year lag) on coconut productivity

Non orthogonal analysis of summer average temperature during one year lag period and coconut productivity indicated that 11.3 % of variability in coconut productivity is explained by summer mean temperature.

The temperature range (difference of between maximum and minimum) during May showed significant negative influence on coconut productivity during the current year, one year, two year, three year lag period (Table 7.4).

Table 7.4: Correlation between temperature range and coconut productivity

Month/season	Current year	Lag period		
		One year	Two year	Three year
January	-0.124	-0.075	-0.221	-0.212
February	-0.116	-0.030	-0.162	-0.092
March	-0.157	-0.084	-0.250	-0.156
April	-0.188	-0.083	-0.156	-0.132
May	-0.401**	-0.369**	-0.325*	-0.269*
June	-0.153	-0.124	-0.171	-0.174
July	-0.196	-0.195	-0.209	-0.142
August	-0.037	0.060	0.051	-0.011
September	-0.220	-0.203	-0.062	-0.130
October	-0.203	-0.217	-0.278*	-0.326*
November	-0.052	-0.079	0.024	-0.057
December	-0.023	-0.023	0.063	0.062
Annual	-0.300*	-0.247	-0.238	-0.160
Summer	-0.326*	-0.334*	-0.252	-0.250
Southwest monsoon	-0.201	-0.125	-0.152	-0.020
Post Monsoon	-0.261	-0.149	-0.231	-0.170
Winter	-0.121	-0.025	-0.150	-0.070

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

The temperature range during October had a negative influence on productivity during two year and three year lag periods. Rest of the months had no significant influence on coconut productivity. The summer temperature range had significant negative influence on coconut productivity during the current year and one year lag period. It was found that, when summer maximum temperature crossed above the average value of 9.2°C during the previous summer, the coconut productivity was below (65.5% of years) average in the following year (Fig.7.4).

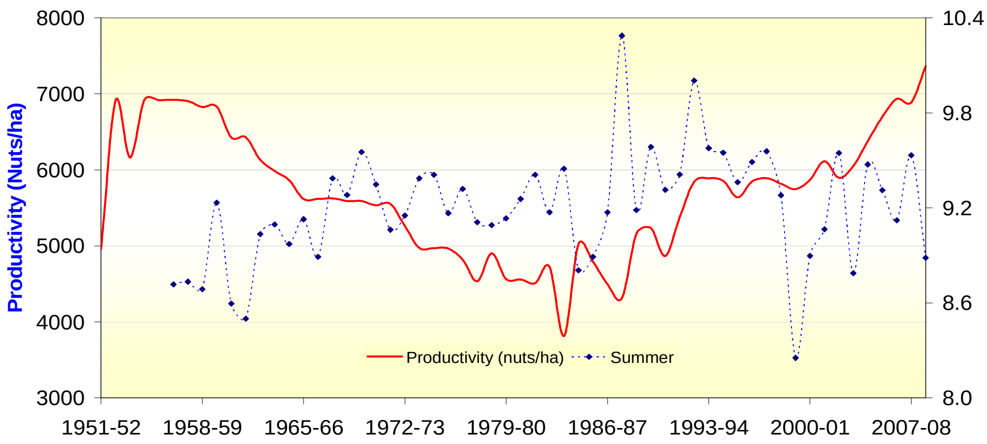


Fig. 7.4: The effect of temperature range during summer (one year lag) on coconut productivity

Non orthogonal analysis of temperature range during summer season one year lag period and coconut productivity indicated that only 9.5% of variability is explained by summer temperature range.

7.1.2 Rainfall

The May rainfall had significant positive influence on coconut productivity during the current year, one year, two year, three year lag period. Rainfall during October had significant positive influence on productivity during one year and three year lag period (Table 7.5). Rest of the months had no significant influence on coconut productivity.

Table 7.5: Correlation between rainfall and coconut productivity

Month/season	Current year	Lag period		
		One year	Two year	Three year
January	-0.068	-0.039	-0.068	0.022
February	0.046	-0.049	0.046	0.111
March	0.231	0.099	0.231	0.227
April	0.159	0.045	0.159	0.227
May	0.325*	0.339**	0.325*	0.322*
June	-0.081	-0.160	-0.081	0.021
July	0.199	0.240	0.199	0.121
August	-0.073	-0.166	-0.073	-0.165
September	0.113	0.118	0.113	0.029
October	0.195	0.320*	0.195	0.323*
November	-0.081	-0.016	-0.081	-0.183
December	-0.016	-0.086	-0.016	-0.123
Annual	0.289*	0.262*	0.227	0.020
Summer	0.396**	0.432**	0.330*	0.311*
Southwest monsoon	0.045	0.038	0.028	-0.190
Post Monsoon	0.244	0.131	0.185	0.190
Winter	-0.074	-0.141	-0.016	-0.070

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

The summer rainfall had significant positive influence on coconut productivity during the current year, one year lag, two year and three year lag period. It was found that, when summer rainfall was below the average value of 404 mm during the previous summer, the coconut productivity was noticed below (58.1% of years) the average in the following year (Fig.7.5).

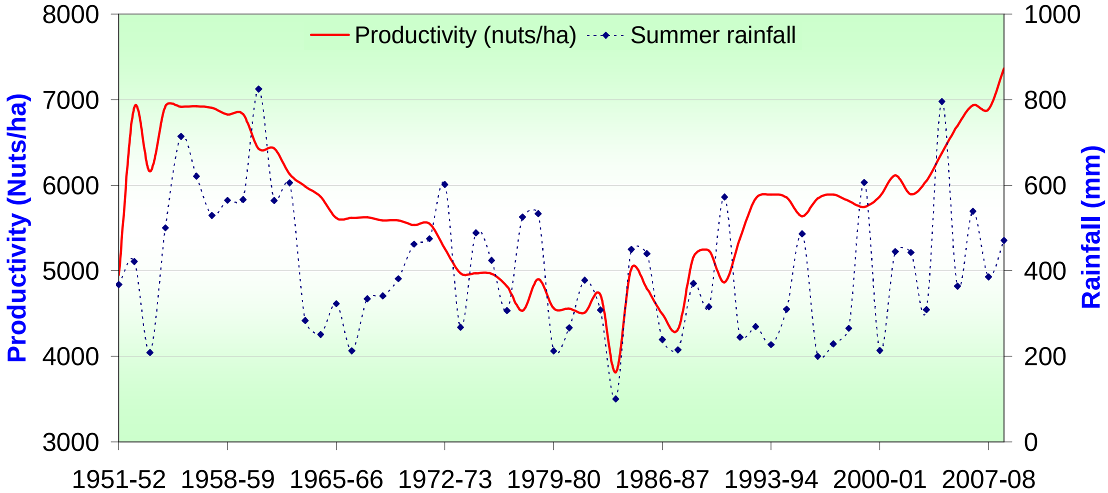


Fig.7.5: The effect of summer rainfall (one year lag) on coconut productivity

Non orthogonal analysis of summer rainfall during one year lag period and coconut productivity indicated that 31.5% of variability is explained by summer rainfall (Fig. 7.6).

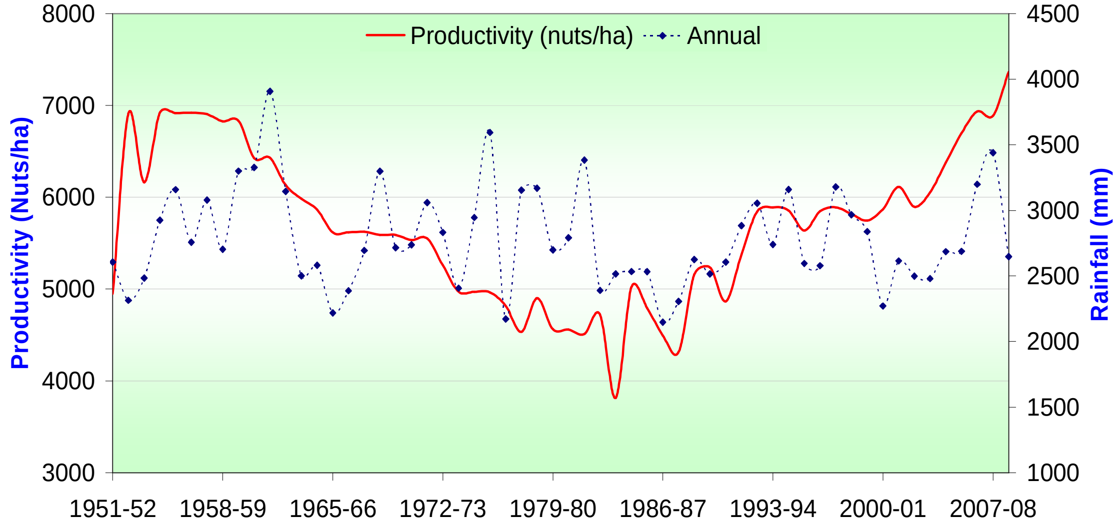


Fig. 7.6: The effect of annual rainfall (one year lag) on coconut productivity

7.1.3 Index of moisture adequacy

Correlations between the index of moisture adequacy during the current year, one, two, three year lag period and coconut productivity indicated that the moisture adequacy during May had significant positive correlation with productivity of one year lag period (Table 7.6). Average index of moisture adequacy from December to May during one year lag period had significant positive correlation with coconut productivity.

Table 7.6: Correlation between index of moisture adequacy and coconut productivity

Month/season	Current year	Lag period		
		One year	Two year	Three year
December	-0.061	0.006	-0.056	-0.147
January	-0.143	-0.034	-0.127	-0.195
February	-0.062	0.092	-0.012	0.011
March	0.035	0.192	0.015	0.009
April	0.152	0.254	0.211	0.186
May	0.184	0.266*	0.121	0.115
Dec-May	0.088	0.296*	0.099	0.050

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

It was observed that the average index of moisture adequacy from December to May, if falls below the mean value of 48%, the coconut productivity is below (48.1% of years) average in the following year (Fig.7.7).

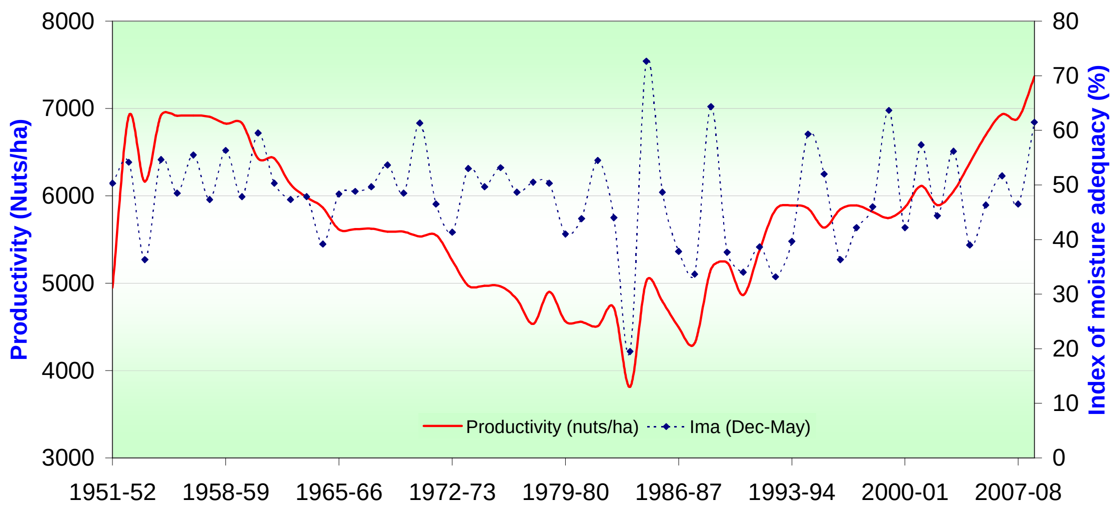


Fig.7.7: The effect of index of moisture adequacy (one year lag) on coconut productivity

Non orthogonal analysis index of moisture adequacy during summer season one year lag period and coconut productivity indicated that index of moisture adequacy explains 16.3% of variation in productivity.

7.1.4 Humidity Index

The correlation between humidity index during current year, one, two, three lag period and coconut productivity indicated that humidity index of August had significant negative influence with productivity of two and three year lag period (Table 7.7). Rest of the months had no significant influence on coconut productivity.

Table 7.7: Correlation between humidity index and coconut productivity

Month/season	Current year	Lag period		
		One year	Two year	Three year
June	0.094	0.074	-0.035	0.095
July	0.129	0.108	-0.008	-0.093
August	-0.166	-0.245	-0.294*	-0.329*
September	0.063	0.094	-0.106	-0.068
June - September	0.092	0.052	-0.152	-0.136

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

It was observed that, when the moisture index of August was below the mean value of 48% during the two year lag period, the coconut productivity was below (48.1% of years) average in the following year. It is possible because the coconut takes 44 months to harvest after inflorescence initiation. Aberrations in weather during different phenophases of coconut will decide final number of nuts if other environmental factors like nutrients, water and temperature are not limiting. It is understood that 40 - 60 per cent of annual coconuts are produced during March, April and May though coconut palm experiences severe soil moisture stress in the absence of rains during the above months. In addition to the above, high incidence of solar radiation results to high maximum air temperature which is not conducive for better coconut production during summer. Despite adverse weather, higher nut yields during summer may be due to favourable environmental conditions that take place at the time of primordium initiation which falls in August, September and October (44 months prior to harvest). Coconut palms in Kerala not only experience severe soil moisture stress during summer but also subjected to waterlogging due heavy rains during monsoon period. The above situation is more predominant in the northern districts of Kerala where a uni - model rainfall pattern is seen.

7.2 YIELD FORECASTING MODELS IN COCONUT

7.2.1 Model based on agro climatic indices

Being a perennial crop with long phenophase of 44 months, advance information on behaviour of coconut yield is of great importance to the Government Agencies, the private Industry, the planners and to the related agencies who involved for the development of coconut industry for follow up action. The studies on crop weather relationships of coconut clearly revealed that both the climatic extremes viz., no rains with high incidence of solar radiation during summer and heavy rains with low amount of solar radiation for about 100 - 120 days during monsoon are detrimental to coconut production. Hence, an attempt has been made to estimate the coconut productivity and yield in coconut based on agroclimatic indices and coconut area. The humidity index during June to September and index of moisture adequacy during October to May were considered along with coconut area one year prior to harvest for predicting coconut production and its productivity seven months ahead. A multiple linear regression was developed using the above agroclimatic indices for predicting coconut production and its productivity seven months ahead. The data from 1961-62 to 2006-07 is used for developing regression equation.

The results indicated that the estimated and actual coconut production was in agreement from 1961-62 to 2006-07. The percentage deviation of coconut production between actual and estimated of any given year during study period was very minimum and negligible. It was true in the case of productivity also (Fig.7.8).

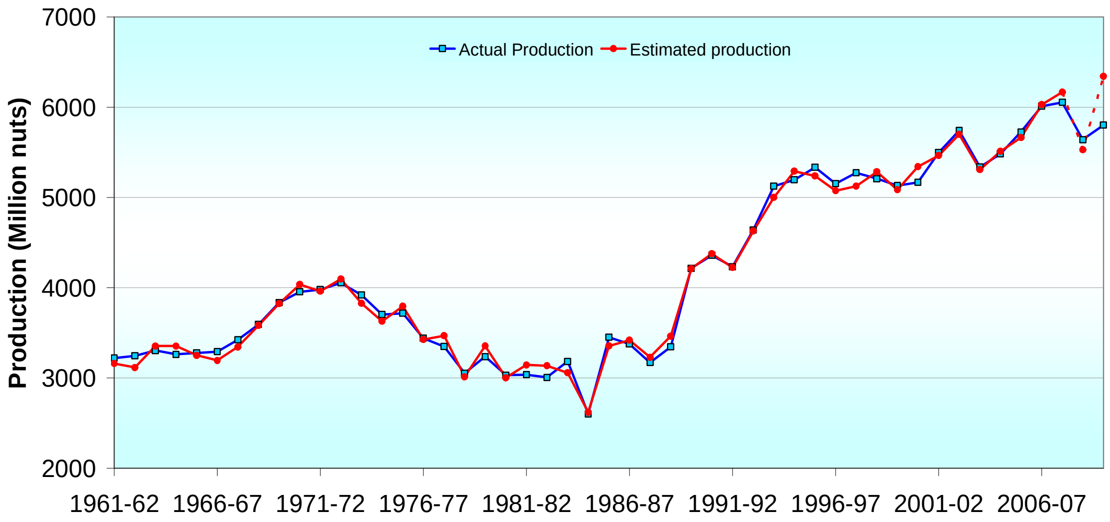


Fig. 7.8: Actual and estimated coconut production from 1961- 62 to 2008-09

In the case of productivity the maximum deviation was noticed during 2007-08 and 1980-81 (4.8% each) followed by 4.2% in 1999-2000 and 4.0 % in 1978-79 (Fig. 7.9).

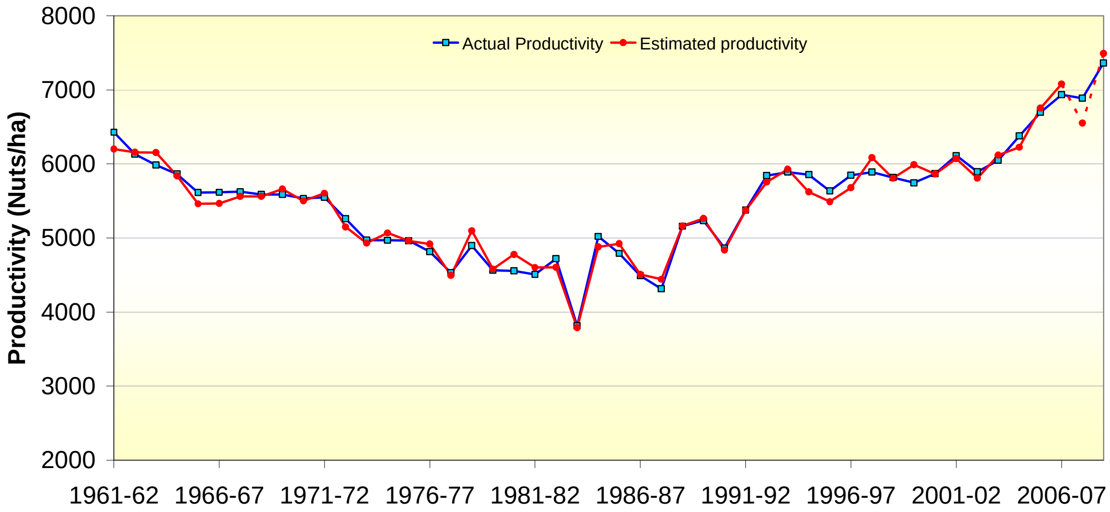


Fig. 7.9: Actual and estimated coconut productivity from 1961- 62 to 2008-09

$$Y= - 34.743*X_1 + 102.872*X_2 + 2.38*X_3 - 0.899*X_4 + 2.54*X_5 - 1.476*X_6 + 7.899*X_7 - 5.371*X_8 + 0.59*X_9 + 3.005*X_{10} -17.129*X_{11} + 8.376*X_{12} - 13.988*X_{13} + 46.678*X_{14} + 5.312*X_{15} - 4.488*X_{16} - 0.549*X_{17} - 1.071*X_{18} + 7.835*X_{19} + 9.975*X_{20} + 1.426*X_{21} + 11.698*X_{22} - 22.258*X_{23} - 32.157*X_{24} + 21.789\ X_{25} + 160.818*X_{26} + 2.947*X_{27} - 5.436*X_{28} + 0.284*X_{29} - 0.739*X30 - 8.88*X_{31} -15.183*X_{32} -16.953*X_{33} + 16.307*X_{34} + 9.02*X_{35} - 11.329*X_{36} + 21.757*X_{37} + 22.987*X_{38} + 2.444*X_{39} - 0.75*X_{40} + 1.17*\ X_{41} - 0.698*X_{42} + 2.265*X_{43} - 24942.3\ (R^2 = 0.969)$$

Where Y= Annual productivity (nuts/ha)

$$Y= - 39.152*X_1 + 160.788*X_2 + 2.362*X_3 - 0.054*X_4 + 1.939*X_5 -1.582*X_6 + 11.229*X_7$$

$$+ 1.197*X_8 + 0.613*X_9 - 5.715*X_{10} - 23.428*X_{11} + 15.58*X_{12} + 0.173*X_{13} + 42.854*X_{14} + 3.713*X_{15} - 3.487*X_{16} - 0.668*X_{17} - 1.301*X_{18} + 14.728*X_{19} + 4.95*X_{20} + 9.612*X_{21} + 7.606*X_{22} - 11.084*X_{23} - 39.304*X_{24} + 33.024*X_{25} + 36.683*X_{26} + 1.971*X_{27} - 4.754*X_{28} - 0.733*X_{29} - 0.573*X_{30} - 4.545*X_{31} - 17.718*X_{32} - 12.114*X_{33} + 11.443*X_{34} + 2.929*X_{35} - 10.818*X_{36} + 35.854*X_{37} + 39.521*X_{38} + 2.137*X_{39} - 0.247*X_{40} + 1.451*X_{41} - 0.601*X_{42} + 7.057*X_{43} - 28700 \quad (R^2 = 0.993)$$

Where Y = Annual production (million nuts)

X_1-X_2 = Ima of October to November of the year of harvest

X_3-X_6 = Ih of June to September of the year of harvest

X_7-X_{11} = Ima of January to May of the year of harvest

X_{12}-X_{14} = Ima of October to December of the previous year of harvest

X_{15}-X_{18} = Ih of June to September of the previous year of harvest

X_{19}-X_{23} = Ima of January to May of the previous year of harvest

X_{24}-X_{26} = Ima of October to December of the two years before harvest

X_{27}-X_{30} = Ih of June to September of the two years before harvest

X_{31}-X_{35} = Ima of January to May of the two years before harvest

X_{36}-X_{38} = Ima of October to December of the three years before harvest

X_{39}-X_{42} = Ih of June to September of the three years before harvest

X_{43} = Coconut area of the previous year of harvest

Using the above equation, the coconut production and productivity of the State of Kerala was estimated for the year 2007-08 and 2008-09 (Table 7.8).

Table 7.8: Actual and estimated coconut production and productivity

Year	Coconut production (Million nuts)			Coconut productivity (Nuts/ha)		
	Actual	Estimated	%deviation	Actual	Estimated	%deviation
2007-08	5641	5529	-2.0	6889	6553	-4.8
2008-09	5802	6344	9.3	7365	7492	1.7
2009-10	-	7509	-	-	9636	-

It indicated that the model output is reasonable as the deviation between the actual and estimated coconut production was within the acceptable limits (< 10%). In the case of coconut production during 2008-09 only, the deviation between the actual and estimated coconut production was 9.3%. When tested further, the deviation between the estimated and actual coconut production was increasing. Such results was reported by Rao and Subash (1996) using same concept based on the data from 1942-43 to 1993-94. The equation developed using the above data was put in test for estimation of the coconut production of the State of Kerala from 1994-95 to 2008-09 (Table 7.9). Though the model worked well in initial years, it totally failed in several years and it was more so in the years 2002-03 and 2003-04 in which the deviation between actual and estimated coconut production was very high (33.3 to 72.9%) as the predicted equation was influenced by abnormal drought during monsoon 2002 and entire rainfall distribution in 2003 and 2004.

Table 7.9: Actual and estimated coconut production of Kerala from 1994-95 to 2009-10

Year	Coconut production of Kerala in million nuts		
	Actual	Predicated	Percentage deviation over actual
1994-95	5335	5110	-4.2
1995-96	5155	4944	-4.1
1996-97	5774	5444	-5.7
1997-98	5209	4651	-10.7
1998-99	5132	3942	-23.2
1999-00	5167	5964	15.4
2000-01	5496	4804	-12.6
2001-02	5744	5289	-7.9
2002-03	5338	4654	-12.8
2003-04	5876	1595	-72.9
2004-05	5727	3820	-33.3
2005-06	6326	7290	15.2
2006-07	6054	6120	1.1
2007-08	5641	6519	15.6
2008-09	5802	6441	11.0
2009-10	-	7390	-

Keeping the above in view, the vector Auto Regression (VAR) was used for prediction of the coconut production and productivity of the State of Kerala.

7.2.2 Vector Auto Regression model

The Vector Auto Regressive model were developed for predicting annual coconut production and productivity of Kerala one year ahead based on average index of moisture adequacy (Ima) from December and the results are summarized below:

The analysis was done using Gretl 1.8 software which is a good package for time series data analysis.

VAR system, lag order 1

OLS estimates, observations 1952-2004 (T = 53)

Log-likelihood = -370.64576, Determinant of covariance matrix = 69477.306

AIC = 14.0998, BIC = 14.2114, HQC = 14.1427

Portmanteau test: LB (13) = 16.6215, df = 12 [0.3255]

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	701.544	249.29	2.8142	0.00698	***
YIELD__millio_1	0.956218	0.0409799	23.3338	<0.00001	***
Ima Dec_may	-9.67718	4.06574	-2.3802	0.02116	**

Mean dependent var	3901.302	S.D. dependent var	919.6766
Sum squared residual	3682297	S.E. of regression	271.3779
R-squared	0.916277	Adjusted R-squared	0.912928
F(2, 50)	273.6034	P-value(F)	1.18e-27
rho	-0.134804	Durbin-Watson	2.049059

F-tests of zero restrictions:

All lags of YIELD__million F (1, 50) = 544.47 [0.0000]

As the results indicate, none of these correlations is significantly different from zero at 5% significance level. This proves that the selected VAR model is an appropriate model. So the fitted VAR model for the coconut yield prediction data based on mean Ima of December to May , one year prior to harvest.

$Y_t = 0.956218*[Y_{t-1}] - 9.67718*[\text{Ima Dec-May}]_{t-1} + 701.544$ (R^2 =0.91)

Where Y_t = Coconut production for the year t in million nuts

Y_{t-1} = Coconut production in the previous year (t-1)

Ima Dec-May = Mean Ima from December to May one year prior to harvest

Model parameters were estimated (Coconut productivity) using SPSS package and presented below.

VAR system, lag order 1

OLS estimates, observations 1952-2004 (T = 53)

Log-likelihood = -393.82384, Determinant of covariance matrix = 166608.15

AIC = 14.9745, BIC = 15.0860, HQC = 15.0174

Portmanteau test: LB (13) = 12.3989, df = 12 [0.4142]

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	1199.12	464.092	2.5838	0.01274	**
Productivity__1	0.877349	0.0790043	11.1051	<0.00001	***
Ima Dec_may	-10.1784	6.58395	-1.5459	0.12843	

Mean dependent var	5604.655	S.D. dependent var	774.3582
Sum squared residual	8830232	S.E. of regression	420.2436
R-squared	0.716805	Adjusted R-squared	0.705478
F(2, 50)	63.27853	P-value(F)	2.01e-14
rho	-0.242335	Durbin-Watson	2.050934

F-tests of zero restrictions:

All lags of productivity F (1, 50) = 123.32 [0.0000]

As the results indicate, none of these correlations is significantly different from zero at 5% significance level. This proves that the selected VAR model is an appropriate model. So the fitted VAR model for the coconut yield prediction data based on mean Ima of December to May , one year prior to harvest.

$Y_t = 0.877349*[Y_{t-1}] - 10.1784*[\text{Ima Dec-May}]_{t-1} + 1199.12$ ($R^2 = 0.71$)

Where Y_t = Coconut productivity for the year t in million nuts

Y_{t-1} = Coconut productivity in the previous year (t-1)

Ima Dec-May = Mean Ima from December to May one year prior to harvest

The equation was developed using the data from 1953-54 to 2004-05. The results indicated that the percentage deviation of coconut production between actual and estimated was maximum (27.6 %) in 1983-84 and followed by 15.1% in 1988-89 and 13.1% in 1984-85 (Fig. 7.10).

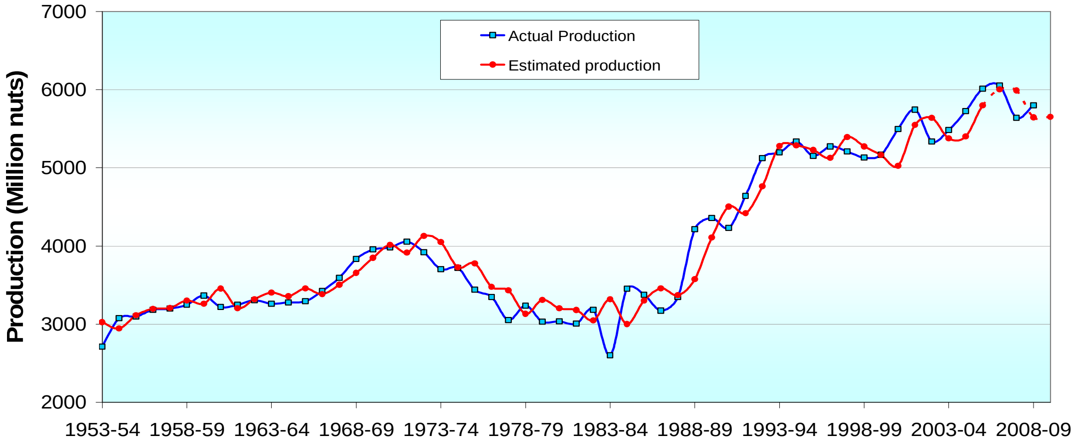


Fig. 7.10: Actual and estimated coconut production from 1953-54 to 2009-10

It indicates the nut yield prediction in coconut may over estimate in abnormal weather event of prolonged summer drought as coconut in 1983-84. It was true in the case of productivity also. In the case of productivity also the maximum deviation was noticed during 1983-84 (28.3 % each) followed by 13.5% in 1984-85 and 11.2 % in 1990-1991 (Fig. 7.11).

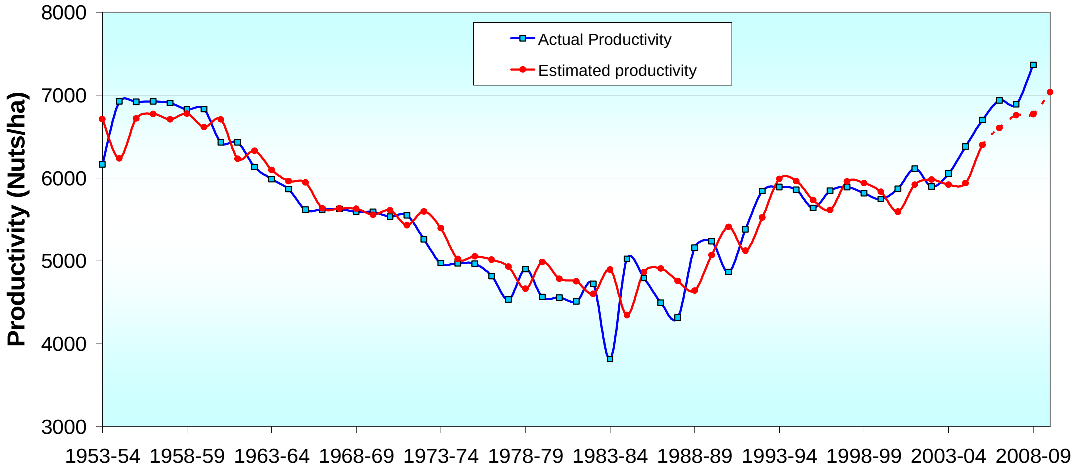


Fig. 7.11: Actual and estimated coconut productivity from 1953-54 to 2009-10

The model was used for predicting coconut production and productivity for 2005-06 onwards and the result is presented in the Table 7.10.

Table 7.10: Actual and estimated coconut production and productivity over Kerala from 2005-06 to 2009-10

Year	Coconut production (Million nuts)			Coconut productivity (Nuts/ha)		
	Actual	Estimated	%deviation	Actual	Estimated	%deviation
2005-06	6013	5800	-3.5	6697	6399	-4.5
2006-07	6054	6003	-0.8	6936	6604	-4.8
2007-08	5641	5991	6.2	6889	6758	-1.9
2008-09	5802	5646	-2.7	7365	6770	-8.1
2009-10	-	5654	-	-	7035	-

It revealed that the predicted and actual coconut production and productivity was almost in agreement from 2005-06 to 2008-09. However, the percentage deviation in coconut production between actual and predicted was maximum (6.2 %) in 2007-08, followed -3.5% in 2005-06 and -2.7% in 2008-09. The least deviation (-0.8%) between actual and predicted coconut production was noticed in 2006-07. In the case of productivity, the percentage deviation between actual and estimate was maximum (-8.1%) in 2008-09 followed -4.8% by 2006-07 and -4.5% in 2005-06. Hence, the Vector Auto Regression (VAR) model can be used for prediction of coconut yield one year head. It can be very well tested for the year 2009-10 during which the predicted coconut production and productivity was 5654 million nuts and 7035 nuts/ha. The actual coconut production and productivity of the State of Kerala is yet to be published.

Chapter VIII

Summary and conclusions

The present investigation on "Coconut Phenology and Yield Response to Climate Variability and Change" was undertaken at the experimental site, at the Regional Station, Coconut Development Board, KAU Campus, Vellanikkara. Ten palms each of eight-year-old coconut cultivars viz., Tiptur Tall, Kuttiadi (WCT), Kasaragod (WCT) and Komadan (WCT) were randomly selected.

The biotic events such as functional leaves, leaf shedding, spathe emergence and its duration, spadix emergence, female flowers and button shedding were recorded weekly from February 2002 to June 2007 along with the daily weather data collected from the same campus. The monthly coconut yield of the experimental coconut palms was also collected for the above period. The published data on annual coconut area, production and productivity from 1950-51 to 2008-09 along with the climatological data were collected for the State as a whole. The past climatological data of rainfall from 1871 to 2009 and temperature data from 1952 to 2009 were collected. The agroclimatic analysis of coconut was carried out using different statistical tools. Phenology of the coconut palm and its response to climate variability were studied. An attempt was also made to study the impact of climate change on coconut production and productivity for the first time in India under the field conditions. The salient results of the study were summarized and presented here:

The annual coconut production was high (75.8 nuts/palm) in Tiptur Tall, followed by Komadan (70.3 nuts/palm) and Kasaragod (65.7 nuts/palm) while it was low (61.5 nuts/palm) in Kuttiadi. It indicated that Tiptur Tall appears to be better among the four cultivars tested in terms of annual coconut production. In all phenological expressions such as functional leaves, leaf shedding, number of spathes, number of spadics and number of female flowers, Tiptur Tall expressed its superiority.

The number of functional coconut leaves present on the crown was low during summer as the coconut leaf shedding is high. The leaf shedding in coconut was less during post monsoon and high during summer while intermediary in southwest monsoon and winter seasons. Rise in ambient temperature, deficit in soil moisture and vapour pressure influence the leaf shedding to a large extent.

The emergence of number of spathes was maximum during post monsoon (1.3/palm/month) while minimum in southwest monsoon season (0.9/palm). The annual number of spathes was low during 2002-03 and 2004-05. It was mainly attributed to summer drought during 2002 and 2004**.** Whenever the summer drought occurred, the spathe emergence in the following season was comparatively low. That is why, the spathe emergence was low during the southwest monsoon in 2002 (0.50/palm/month) and 2004 (0.68/palm/month) against the average number of 0.85/palm/month.

The duration of spathe in all the cultivars was minimum (9.6 weeks) if it emerged in southwest monsoon while it was maximum (10.9 weeks) in winter, followed by summer (10.3 weeks) and post monsoon (10.2 weeks). The spathe duration during summer took more than ten weeks on an average, which was intermediary. The reasons for the maximum spathe duration during winter season can be attributed to low minimum temperature, relative humidity, high temperature range, wind speed, vapour pressure deficit, evaporation and sunshine hours prevailed when compared to other seasons. The spathe duration during 2004-05 was low (10 weeks) when compared to that of other years. It was mainly attributed to the well distributed rainfall with adequate soil moisture along with optimum maximum and minimum temperatures and low vapour pressure deficit.

The effect of seasonality on number of spadices indicated that that it was less during post monsoon (0.8/palm/month) and high (1.4/palm/month) during summer when compared to that of southwest monsoon (0.9/palm/month) and winter

(1.0/palm/month). The cumulative effect of more spathe emergence and its duration during post monsoon, followed by winter led to more spadix production in summer. It can be attributed to the fact that high rainfall 32 months before (July-September) the spadix production coincide with the receipt of southwest monsoon rainfall was optimum, which resulted in better availability of soil moisture. It may favour congenial environment for the primordium initiation and thus maximum spadix production during summer season. The unfavourable weather conditions such as low rainfall, number of rainy days and high temperature coupled with more sunshine hours 32 months prior to the spadix production (February- March) would have played a major role in low number of spadix production during the post monsoon season.

The number of female flowers produced during the summer was high (47.2 female flowers/bunch), while it was minimum (only 22 female flowers/bunch) during the post monsoon season (October-November). A gradual decline in female flower production was noticed from summer to post monsoon season and thereafter an increase was noticed during winter in all the cultivars. It revealed that the trend in female flower production was uniform in all the cultivars despite varietal difference.

The effect of weather variables during the two critical stages viz., primordia initiation and ovary development is vital for final female flower production. These above phases coincide with 32 months and 6-7 months, respectively prior to the spadix emergence.

The seasonal variation in button shedding indicated that it was maximum (73.6%) during winter (December- February) and low during southwest monsoon (61.5%) and post monsoon season (61.1%). There was no significant variation between post monsoon and southwest monsoon seasons in button shedding. The button shedding is high when the temperature and vapour pressure deficit were high under the moisture stress conditions. The abiotic factors that are involved in the case of button shedding are temperature, vapour pressure deficit and soil moisture deficit. High temperature, both air and soil, and vapour pressure deficit adversely influenced the button shedding in coconut in absence of soil moisture. It is evident during the summer. The low button shedding from June to November could be attributed to less vapour pressure deficit in the crop environment under no soil moisture stress. When all the biotic and abiotic factors are considered, the seasonal variation in button shedding is predominantly influenced by soil moisture and vapor pressure deficit along with the number of female flowers.

The study of ontogeny of coconut revealed that the total rainfall, number of rainy days and the total dry spell are not as crucial as the length of dry spell at the critical stages such as primordium initiation, ovary development and button size nuts which ultimately determine the yield potential of rainfed coconut palms. It also revealed that primordium stage was most sensitive to moisture stress, followed by ovary development stage and the stage of button in coconut

The decline in coconut production due to severe summer drought could be seen in the following year under rainfed conditions though the annual coconut production depends upon the weather factors three - and - a - half - years ahead. Similarly, good summer showers with less duration of dry spell are likely to influence the coconut yield favourably in the following year to a considerable extent. On examination of the effect of drought on monthly nut yield at various locations across Kerala, it is clear that the effect of drought on monthly nut yield commenced in the seventh, eighth or nineth month after the drought period was over in May or June, depending upon the receipt of pre-monsoon showers or onset of monsoon. The effect of summer drought on coconut yield continued for twelve months. Decline in monthly nut yield was maximum in 12^{th} /13^{th} month after the drought period was over. The lowest coconut production/productivity over Kerala was noticed during 1983-84 due to disastrous summer drought in 1983. Similar was the case in 2002-03 and 2004-05. Majority of drought years showed decline in yield in the following year. This could be explained due to the sensitiveness of various critical crop growth stages to soil moisture stress, which finally decides nut yield in coconut. The coconut production under rainfed conditions is influenced significantly by the length of dry spell in various critical stages. The availability of adequate soil moisture during the primordium initiation stage, ovary development stage and button size nut stages are the most crucial for final harvest of coconuts. A multiple regression model (R^2 = 0.78) was developed for predicting the monthly coconut yield at farm level based on weather variables at critical stages. The results indicated that the actual and estimated values were in good agreement. The Vector Auto Regression (VAR) model can also be used for prediction of coconut yield one year head provided it is tested and revalidated from time to time.

The climate change studies indicated that the monthly rainfall showed a significant decreasing trend during June and July while increasing trend during October and November. The contribution of monthly rainfall to annual value was also declining in June and July while increasing in August, September, October and December. There was a significant increasing trend in rainfall during post monsoon season while decreasing trend during southwest monsoon season. A sort of rainfall shift was noticed as monsoon rainfall was declining while post monsoon rainfall was increasing.

The monthly maximum temperature showed significant increasing trend in all the months except April. In the case of minimum temperature, July only showed significant increasing trend while in the remaining months the trend was not statistically significant. The trend in temperature range during January, February, March and December was not significant while remaining months showed significant increasing trend.

The annual aridity index over Kerala showed a significant increase during the last 109 years (1901-2009). The intensity of droughts was high in recent decades of 1981-90 and 1991-2000 during which severe and disastrous droughts were noticed. The moisture index was in decreasing trend from 1901 to 2009, indicating that Kerala state is moving from wetness to dryness in recent decades.

Conclusions and recommendations

The study therefore, reinforces our traditional knowledge that the coconut palm is sensitive to changing weather conditions during the period from primordium initiation to harvest of nuts (about 44 months). Absence of rainfall from December to May due to early withdrawal of northeast monsoon, lack of pre monsoon showers and late onset of southwest monsoon adversely affect the coconut productivity to a considerable extent in the following year under rainfed conditions. The productivity can be increased by irrigating the coconut palm during the dry periods.

Increase in temperature, aridity index, number of severe summer droughts and decline in rainfall and moisture index were the major factors for a marginal decline or stagnation in coconut productivity over a period of time, though various developmental schemes were in operation for sustenance of coconut production in the State of Kerala. It can be attributed to global warming and climate change. Therefore, there is a threat to coconut productivity in the ensuing decades due to climate variability and change. In view of the above, there is an urgent need for pro-active measures as a part of climate change adaptation to sustain coconut productivity in the State of Kerala.

The coconut productivity is more vulnerable to climate variability such as summer droughts rather than climate change in terms of increase in temperature and decline in rainfall, though there was a marginal decrease (1.6%) in the decade of 1981-2009 when compared to that of 1951-80. This aspect needs to be examined in detail by coconut development agencies such as Coconut Development Board and State Agriculture Department for remedial measures. Otherwise, the premier position of Kerala in terms of coconut production is likely to be lost in the ensuing years under the projected climate change scenario.

Among the four cultivars studied, Tiptur Tall appears to be superior in terms of reproduction phase and nut yield. This needs to be examined by the coconut breeders in their crop improvement programme as a part of stress tolerant under rainfed conditions.

Crop mix and integrated farming are supposed to be the best combination to sustain development in the long run under the projected climate change scenarios. Increase in coconut area under irrigation during summer with better crop management and protection measures also are necessary measures to increase coconut productivity since the frequency of intensity of summer droughts is likely to increase under projected global warming scenario.

Future line of work

- Coconut phenology can be understood better if more detailed investigations are taken up under varied agroclimates in rainfed and irrigated conditions across the coconut growing regions.
- The effect of droughts on coconut yield should be studied further in detail with varied crop management practices and varieties as their phenology and responses to stress conditions under field conditions are different.
- Studies on short and long term impacts of climate change need to be understood through crop growth simulation models on a priority basis.
- The various statistical models developed at various coconut research centres need to be tested and made use of for operational purposes along with crop simulation models.

REFERENCES

Abeywardena, V. 1955. An agri-meteorological project at the coconut research institute. *Ceylon Cocon.Q*. 6:97-98

Abeywardena, V. 1968. Forecasting coconut crops using rainfall data-a preliminary study. *Ceylon Cocon. Q*. 19: 161-176

Abeywardena, V. 1971. Yield variation in coconut. *Ceylon Cocon. Q.* 22:97-103

Abeywardena, V. 1983. Effect of moisture stress and irrigation on yield of coconut in Sri Landa. In *Coconut Research and Development*, 98-106 (Ed. N. M. Nayar). New Delhi: Wiley Eastcon

Abeywardena, V. and Fernando, J.K.T. 1963. Seasonal variation of coconut crops. *Ceylon Cocon.Q.* 6:74-88

Abeywardena, V. and Mathes, D.T. 1971. Crop loss in coconut through button shedding and immature nutfall. *Ceylon Planters Review* 6: 161-176

Aggarwal, P.K. 2003, Impact of climate change on Indian agriculture. *J. Plant Biology* 30 (2), 189-198

Ananthakrishnan, R., Soman, M.K. 1988. The onset of the Southwest monsoon over Kerala: 1901-1980. *Int. J. of Climatol*. 8: 283-296

Ananthakrishnan, R., Soman, M.K. 1989. Onset dates of the Southwest monsoon over Kerala for the period 1870-1900. *Int. J. of Climatol*. 9: 321-322

Babu, K.S., Asan, R.B.,Bhaskaran, C. and Kumar, N.M. 1993. Coconut yield response to monthly rainfall. *Indian Cocon. J*.23: 8-10

Babu, K.S. and Sebastian, M. 1996. Seasonal price behaviour in coconut and coconut products: An economic approach. *Indian Cocon. J.* 26 (9): 14-18

Bai, K.V.K., Reddy, S.D.V., Ratnambal, M.J. and Laxman, R.H. 2003. Factors contributing to female flower production and button shedding in coconut. *J. plantation crops* 31(2):33-36

Bai, K.V.K., Voleti, S.R. and Rajagopal, V. 1988. Water relations of coconut palm as influenced by environmental variables. *Agric.. Forest Meteorol*. 43: 193-199

Baier, W. 1977. Crop weather models and their use in yield assessments. Technical Note No. 151.WMO.Geneva, 48pp

Balakrishnan, M., Meena, K and Rao, G.S.LH.P. 2005. Forecasting of coconut yield using artificial neural network. In. proceedings of national workshop on drought management in plantation crops organized by Kerala Agricultural University, Thrissur on 22- 23, March. pp 75-79

Bhaskaran, B. Mitchell, J. F. B., Lavery, J. R. and Lal, M. 1995. Climatic response of Indian subcontinent to doubled CO2 concentrations. *Int. J. of Climatol.* 15: 873-892

Bhaskaran, U.P. and Leela, K. 1976. Seasonal influence on yield of Tall x Dwarf and West Coast Tall. Paper presented in the international Symposium on Coconut Research and Development. 1976

Bhaskaran, U.P. and Leela, K. 1977. Water management in coconut. *Indian Cocon. J .8(5)*: 1-4

Bhaskaran, U.P. and Leela, K. 1983. Seasonal influence on yield of Tall x Dwarf and West Coast Tall coconuts in Kerala, India. *Coconut Research and Development*. (ed. Nayar, N.M.). Wiley Eastern Ltd., New Delhi, p. 518

Central water commission. 1982. Reports on identification of drought prone areas for 99 districts. New Delhi

Child, R.1964. *Coconuts.* Longmans, London, p.216

Chowdhury, A., Dandekar, M.M and Raut, P.S. 1989. Variability in drought incidence over India- A statistical approach, Mausam 40(2):207-214

Coomans, P. 1975. Influence of climatic factors on the seasonal and annual fluctuation in coconut yield. *Oleagineux* 30:153-159

Copeland, F.B. 1931. *The Coconut*. Mc Milan and Co., London, p. 307

Dash, S. K. and Hunt, J. C. R. 2007. Variability of climate change in India, *Curr. Sci., 93*(6):782-788

Davis, T.A. and Gosh, S.S. 1982. Forecasting of coconut yield using rainfall data. *Indian Cocon.J.* 8:3-7

De Wit, C.T. 1965. *Photosynthesis of leaf canopies: Agricultural Research Report.* No.663. Wageningen, Netherland, p.56

De, U.S. and Joshi, K.S., 1998. Natural Disasters and their impacts on developing countries, WMO Bulletin, 47(4): 336-343

De, U.S., Dube, R.K. and Prakasa, Rao. G. S. 2005. Extreme Weather Events over India in the last 100 years. J. Ind. Geophys. Union. 9 (3): 173-187

Doorenbos, J. and Pruitt, W.C. 1975. Guidelines for predicting crop water requirements. Irrigation and Drainage Paper No: 24. *Food and Agricultural Organization*, Rome, p.197

Dracup, J. A., Lee, K. S., and Paulson Jr, E. G., 1980. On the Definition of Droughts. *Water Resources Research*, 16(2): 297-302

Draper, N.R. and Smith, H. 1996. *Applied Regression Analysis*. John Wiley and Sons, New York, pp. 54-104

Francis, P. A., and Gadgil, S. 2006. Intense rainfall events over the west coast of India, Meteorol. Atmos. Phys., 94: 27- 42, doi:10.1007/s00703- 005-0167-2

Frere, M. and Popov, G.F. 1979. Agrometeorological crop monitoring and forecasting. Plant Production and Protection Paper No: 17. *Food and Agricultural Organization*, Rome, p.117

Gadd, C.H. 1923. Nut fall of coconut. *Ceylon Dept. Agric. Bull.* 53: 5-6

Gadgil, A. and Dhorde , A. 2005. Temperature trends in twentieth century at Pune, India. Atmospheric Environment, 39: 6550-6556

Gangolly, S.R. 1953. A resume of investigation on shedding button in coconut. *Indian Cocon.J*. 6:60-66

Gangolly, S.R., Gopalakrishnan, T.P. and Satyanarayana, B.S. 1956. Investigation on shedding button in coconut. *Indian Cocon. J*. 9:135-160

Garg, A., shukla, P.R., Bhattacharya, S. and Dadhwal, V. K. 2001. Sub-region (district) and sector level SO_2 and NO_2 emissions for India: assessment of inventories and mitigation flexibility. *Atmospheric Environment* 35: 703-713

Gadhavi, B.K., Khunt, K.A. and Gajipara, H.M. 2001. Price behaviour of coconut in Saurashtra region of Gujarat State. *J. of plantation crops*, 29 (2):60-63

George, K.C. 1988. Forecasting models for the yield of coconut. *Agrometeorology of Plantation Crops.* Proceedings of the national seminar (eds. Rao, G.S.L.H.V.P. and Nair, R.R.) March 12-13, 1987, Kerala Agricultural University, Thrissur, pp.12-13

Gore, P.G., Prasad, T and Hatwar, H.R. 2010. Mapping of drought areas over India, NCC Research Report. N0.12, India Meteorological Department, Pune

Gore, P.G. and K.C. Sinha Ray. 2002. Variability in drought incidence over districts of Maharashtra, Mausam, 53, pp 533-542

Goswami P and Gouda, K.C. 2007. Advance Dynamical Forecasting of Onset of Monsoon Rainfall over India. In: Proceedings of Int. Conf on Asian Variability during the Past Global Changes (AMV-PGC), Kumaun University, Nainital, 11-14 September 2007

Gregory, S. 1989. The changing frequency of drought in India: 1871-1985. *The Geographical Journal*, 153(3): 322-334

Guhathakurta, P. and Rajeevan, M. 2008. Trends in the rainfall pattern over India, *Int. J. of Climatol*. 28: 1453–1469, doi:10.1002/joc.1640

Haggerty, B.P. and Mazer, S. J. 2008. The Phenology Handbook. University of California, Santa Barbara. P41

Hargreaves, G.H. 1977. World Water for Agriculture. Utah State University, p.177

Haridoss, R and Chandran, C. 1997. Price behaviour of coconut and coconut oil in Tamil Nadu. *Indian Cocon. J*. 27 (10):5-7

Harries, H.C. 1977. The cape verde region (1499 to 1549): The key to coconut culture in the western Hemisphere Turrialbe Quart. 31: 227-231

Hingane, L. S., Kumar, K.R and Murthy, B.V.R. 1985. Long-term trends of surface air temperature in India, *J. Climatol.* 5: 521-528

IPCC (Intergovernmental Panel for Climate Change). 2001. Climate Change *2001* - The Scientific Basis, Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change

IPCC (Intergovernmental Panel for Climate Change). 2007. Climate Change 2007: The Physical Science Basis IPCC Working Group I

IPCC (Intergovernmental Panel for Climate Change). 2007. Climate Change 2007: Impacts, Adaptation and Vulnerability IPCC Working Group II

Jacob Mathew, C. H., Vijaya Kumar, K., Nambiar, P. T. N. and Amaranath, C. H. 1991. Forecasting of annual yield of coconuts based on biometrical characters. *Coconut Research and Development* 7(1): 24-34

Jagannathan, P. and Bhalme, H.N. 1973. Changes in pattern of distribution of southwest monsoon rainfall over India associated with sunspots. Monthly Weather Review 101: 691 - 700

Jagannathan, P., Parthasarathy, B. 1973. Trends and periodicities of rainfall over India. Monthly Weather Review 101: 3711 - 375

Jose, A.I., Krishnakumar, N. and Gopi, C.S. 1991. Yield prediction in coconut based flower nutrient level. In: coconut Breeding and Management (Eds. Sailas E. G, Aravindakshan m and Jose A.T). Kerala Agricultural University pp 212-218

Joseph, P.V., Simon, A., Nair, V.G. and Thomas, A. 2004. Intra-Seasonal Oscillation (ISO) of south Kerala rainfall during the summer monsoons of 1901-1995. In: Proceedings of the Indian Academy of Sciences (Earth Planetary Sciences), 113 (20): 139-150

Kalathiya, K.V. and Sen, N.L. 1991. Correlation among floral and yield characteristics in coconut, variety Dwarf Green. *Coconut Breeding and Management* (eds. Silas, E.G., Aravindakshan, M. and Jose, A.I.). Proceedings of National Symposium on Coconut Breeding and Management, 1988. Kerala Agricultural University, Thrissur, pp.116-117

Karunanithi, K., Karhikeyan, M., Sarala, L., Mohandas, S. and Rajarethinam, S. 2002. Button shedding in coconut: causes and remedies. *Indian Cocon.J.* 32:10-12

KAU. 2007. *Package of Practice Recommendations crops-2007.* Directorate of Extension, Kerala Agricultural University, Thrissur, p.334

Keeling, C. D., Whorf, T. P., Wahlen, M. M., and Plicht, J.V.D. 1995, Interannual extremes in the rate of rise of atmospheric carbon dioxide since 1980. *Nature* 375: 666–670

Kothawale, D.R., and Kumar, K.R. 2005. On the recent changes in surface air temperature trends over India. Geophys. Res. Lett. 32, L18714, doi: 10.1029/2005GL023528r

Kotteswaram, Alvi, S.M.A. 1969. Secular trends and periodicities in rainfall at west coast stations in India. Curr. Sci. 101: 371-375

Krishnakumar, K.N., Rao, G.S.L.H.V.P. and Gopakumar, C.S. 2008. Climate change at selected locations in the humid tropics. *J. Agrometeorol.,* 10(1): 59-64

Krishnakumar, K.N, Rao, G.S.L.H.V.P and Gopakumar, C.S. 2009. Rainfall trends in twentieth century over Kerala, India. Atmospheric environment 43: 1940-1944

Krishnakumar, K.N., Rao, G.S.L.H.V.P., Gopakumar, C.S. and Mohan, H.S.R. 2007. Rainfall variability during southwest monsoon over Kerala (India): 1971-2005. Indian Journal of Polar Sciences, 1: pp81-87

Krupa, S. 2003. Atmosphere and agriculture in the new millennium. *Environmental Pollution,* 126: 293-300

Kumar, K.R. and Hingane, L.S., 1988. Long-term variations of surface air temperature at major industrial cities of India. *Climatic Change,* 13: 287-307

Kumar, K.R, Pant, G. B., Parthasarathy, B. and Sontakke, N. A. 1992. Spatial and subseasonal patterns of the long-term trends of Indian summer monsoon rainfall', *Int. J. of Climatol.* 12: 257-268

Kumar, K.R., Krishna Kumar, K. and Pant, G. B.1994. Diurnal asymmetry of surface temperature trends over India. *Geophy. Res. Let.* 21: 677-680

Kumar, K.R and Ashrit, R.G. 2001. Regional Aspects of global climate change simulations: Validation and assessment of climate response over Indian monsoon region to transient increase of greenhouse gases and sulphate aerosols. *Mausam* 52, 1, 229-244

Kumar, K .R., Kumar, K. K., Ashrit, R. G., Patwardhan, S. K. and Pant, G. B. 2002. Climate change in India: Observation and Model Projections. Climate change and India: Issues, Concern and Opportunities (eds. Shukla, P.R., Sharma, K.S. and Ramana, P.V.). Tata McGraw-Hill Publishing Company Limited, New Delhi, pp 24-75

Kumar, K.R., Kumar, K., Prasanna, V., Kamala, K., Desphnade, N. R., Patwardhan, S. K. and Pant, G.B. 2003. *Future climate scenario, In: Climate Change and Indian Vulnerability Assessment and Adaptation*. Universities Press (India) Pvt Ltd, Hyderabad, 462 pp

Kumar, S.N., Bai, K. V.K., Rajagopal, V. and Aggarwal P. K. 2008. Simulating coconut growth, development and yield with the Info Crop-coconut model. *Tree Phys.* **28**: 1049-1058

Kumar, S.N., Rajagopal, V, Thomas, S., Cherian, V.K., Narayan, R., Ananda, K.S., Nagwekar, D.D., Hanumanthappa, M., Vincent, C. and Srinivasalu, B. 2007. Variation in nut yield of coconut and dry spell in different agro-climatic zones ofIndia. *IndianJournal of Horticulture* 64(3): 309-313.

Kumar, S.N., Rajeev, M.S., Vinayan**.,** Nagvekar, D.D., Venkitaswamy, R., Rao, D.V.R., Boraiah, B., Gawankar, M. S., Dhanapal, R., Patil D.V. and Bai. K.V.K. 2009. Trends in weather and yield changes in past in coconut growing areas in India. *J. Agromet.* **11:** 15-18.

Kumar, S.N. and Aggarwal, P.K. 2009. Impact of climate change on coconut plantations . Global Climate Change and Indian Agriculture, Case Studies from the ICAR Network Project. ICAR, New Delhi. Pp 24-27

Kutty, M.C.N. and Gopalakrishnan, P.K. 1991. Yield components in coconut palms. *Coconut Breeding and Management* (eds. Silas, E.G., Aravindakshan, M. and Jose, A.I.). Proceedings of National Symposium on Coconut Breeding and Management, 1988. Kerala Agricultural University, Thrissur, pp. 94-98

Lal, M., Nozawa, T., Emori, S., Harasawa, H., Takahashi, K., Kimoto, M., Ouchi, A.A., Nakajima, T., Takemura, T. and Numaguti, A. 2001. Future climate change: Implications for Indian summer monsoon and its variability. *Curr. Sci.* 81: 1196-1207

Lal, M., Cubasch, U., Voss, R and Waszkewitz. J. 1995. Effect of transient increases in greenhouse gases and sulphate aerosols on monsoon climate. *Curr. Sci.* 69(9): 752–763

Libiseller, C. and Grimall, A. 2002. Performance of partial Man-kendall Test for trend detection in the presence of covariates, Environmetrics 13.pp. 71-84

Lonergan, S. 1998. Climate warming and India, In Measuring the Impact of Climate Change on Indian Agriculture, (eds. Dinar, A et. *al*.,) Washington DC: World Bank Technical Paper No. 402

Louis, H. and Annappan, R.S. 1980. Environmental effects on yield of coconut palm. *Indian Cocon. J.* 12:1-4

Mahindapala, R. 1984. Measures to minimize drought damage in coconut plantations. Coconut Bulletin 1(1):1-4

Marar, K.M.M. and Pandalai, K.M. 1957. Influence of weather factors on coconut crop. *Indian J .Met .Geophysics* 8:60-70

Marar, K.M.M. and Pandalai, K.M. 1959. Observations from some long-term experimental plots of coconuts. *Indian Cocon. J.* 13:1-24

Marechal, H. 1928. Floral biology and pollination. *Agric. J. Fiji*, 32:5-6

Menon, K.P.V. and Pandalai, K.M. 1958. *The Coconut Palm: A Monograph*. Indian Central Coconut Committee, Ernakulam, p.384

Mooley, D.A., Parthasarathy, B. 1983. Variability of Indian summer monsoon rainfall and tropical circulation features. Monthly Weather Review 111: 967- 968

Mooley, D.A., Parthasarathy, B. 1984. Fluctuations in All - India summer monsoon rainfall during 1871 - 1978. Climate change 6: 287-301

Naidu, C.V., Rao, B.R.S, Rao, D.V.B. 1999. Climatic trends and periodicities of annual rainfall over India. Meteorol. Appl. 6: 395-404

Nair, B.P. and Unnithan, V.K.G. 1988. Influence of seasonal climatic factors on coconut yield. *Agrometeorology of Plantation Crops.* Proceedings of the national seminar (eds. Rao, G.S.L.H.V.P. and Nair, R.R.) March 12-13, 1987, Kerala Agricultural University, Thrissur, pp.118-123

Nambiar, M.C., Sreedharan, A. and Sankar, N. 1969. Preliminary observation on growth and likely effect of seasons on nut development in coconut. *Indian J. Agric. Sci*. 39: 455-461

Nambiar, N.P.K. and Rao, G.S.L.H.V.P. 1991. Varietal and seasonal variation in oil content of coconut. *Coconut Breeding and Management* (eds. Silas, E.G., Aravindakshan, M. and Jose, A.I.). Proceedings of National Symposium on Coconut Breeding and Management, 1988. Kerala Agricultural University, Thrissur, pp. 283-286

NATCOM Report. 2004. Ministry of Environment and Forests, New Delhi, Govt. of India

Nelliat, E.V and Padmaja, P.K. 1978. Irrigation requirements of coconut and response to levels of fertilizer under irrigated conditions during the early bearing stage. In: PLACROSYM I. Agronomy, soils physiology and economics of plantation crops. (ed. Nelliat, E.V). Proceedings of the First Symposium on Plantation Crops, Indian Society for Plantation Crops, Kasaragod, pp. 186-199

Pai D.S. and Rajeevan, M. 2006. Empirical prediction of Indian summer monsoon rainfall with different lead periods based on global SST anomalies. *Meteorol. Atmos. Phys.* 92: 33- 43

Pai, D.S., Sridhar, L., Guhathakurta, P. and Hatwar. H. R. 2010. District-Wise Drought Climatology Of The Southwest Monsoon Season over India Based on Standardized Precipitation Index (SPI). NCC Research Report No.2/2010.22p

Palaniswami, C., Dhanapal, R., Upadhyay, A.K. and Manojkumar, C. 2008. A fuzzy neural network for coconut yield prediction. *J. of plantation crops*, 36(1):24-29

Pant, G.B., Kumar, K. R., 1997. Climate of South Asia. John Wiley and sons, Chichester, pp 320

Parathasarathy, B., Sontake, N.A., Mont, A.A. and Kothawale, D.R. 1987. Drought flood in summer monsoon season over different meteorological subdivisions of India for the period 1971-1984. *J. Climatol*., 7, 57-70

Park, M. 1934. Some notes on the effect of drought on the yield of coconut palm. *Trop. Agric*. 83:141-150

Parthasarathy, B. 1984. Inter annual and long term variability of Indian summer monsoon rainfall. Proceedings of the Indian Academy of Sciences (Earth Planetary Sciences) 93: 371-385

Parthasarathy, B., Dhar, O.N. 1978. Climate fluctuations over Indian region – Rainfall: a review. Research Report no. RR-025. Indian Institute of Tropical Meteorology, Pune, 31

Parthasarathy. B., Kumar, K.R., Munot, A.A. 1993. Homogeneous Indian monsoon rainfall: variability and prediction. Proceedings of the Indian Academy of Sciences (Earth Planetary Sciences) 102: 121-155

Patel, J.S. 1938. *The Coconut: A Monograph*. Government press, Madras, p. 312

Patel, J.S. and Anandan, A.P. 1936. Rainfall and the yield in coconut. *Madras Agric. J.* 24:5-15

Peris, T.S.G. 1989. Forecasting the crop yield of coconut estate. Coconut Research Development , 52:67-76

Peiris, T. S. G and Thattil, R.O. 1998. The study of climate effects on nut yield of coconut using Parsimonious models. Experimental Agriculture, 34:189-206.

Peiris, T. S. G. 1991. Relationship between coconut yield and rainfall at Ratmalagara. In *Annual Report of the Coconut Research Institute of Sri Lanka.* Sri Lanka: CRI.

Peiris, T.S.G. 1993. The degree of influence of rainfall on coconut. *Coconut Research and Development* (ed. Nayar, N.M.). Wiley Eastern Ltd., New Delhi, pp.413-419

Peiris, T. S. G., Hansen, J.W. and Zubair, L. 2008. Use of seasonal climate information to predict coconut production in Sri Lanka. *Int. journal of climatol*. 28: 103-110

Peiris, T.S.G., Thattl, R.O. and Mahindapala, R. 1995. An analysis of the effect of climate and weather on coconut (Cocos Nucifera). *Expl. Agric*. 31:451-463

Pillai, P. B., Nayar, P. S. and Rao, A. V. R.K. 1988. Influence of rainfall on coconut yield. *Agrometeorology of Plantation Crops*. (eds. Rao, G.S.L.H.V.P. and Nair, R.R.). Proceedings of the National Seminar, March 12-13, 1987. Kerala Agricultural University, Thrissur, pp144-146

Pillai, V.R. and Satyabalan, K. 1959. A note on the seasonal variation in yield, nut characters and copra content in a few cultivars of coconuts. *Indian Cocon. J.* 13 (2): 45-55

Prabhakaran, P.V., Balachandran Nair, G.K., Thampi, P., Pillai, K.S., Nair, V.R., Nair, G.M., Pushpangadan, K., Sukumaran, K.M., Pillai, E.R. and Koshy, E.P. 1991. Forecast of coconut yield using morphological characters of young palms. In: coconut Breeding and Management (eds. Sailas, E.G, Aravindakshan, M. and Jose, A.T). Kerala Agricultural University, pp 243-246

Pramanik, S.K., Jagannathan, P. 1954. Climate change in India -1: Rainfall. Indian journal of Meteorology Geophysics 4: 291 – 309

Purseglove, J.W. 1972. Tropical Crops: Monocotyledons. Longmans, London. pp540

Purseglove, J.W. 1968. Moraceae. *In* Tropical crops, dicotyledons 2. Longman Group Ltd., London. pp.379 - 384

Rajagopal, V., Shivasankar, S. and Mathew, J. 1996. Impact of dry spells on the ontogeny of coconut fruits and its relation to yield. *Planation Res.Dev.* 3: 251-255

Rajeevan M., 2001. Prediction of Indian summer monsoon: Status, problems and prospects. *Curr. Sci. India* 81: 1451-1457

Rajeevan M., Bhate, J., Kale, J. D. and Lal, B. 2006. High resolution daily gridded rainfall data for the Indian region: Analysis of break and active monsoon spells. *Curr. Sci. India* 91: 296-306

Raju P. V., Raju, S., Mohanty, U. C. and Bhatla, R. 2007. Interannual variability of onset of the summer monsoon over India and its prediction. *Nat. Hazards* 42: 287-300

Ramesh, K. V. and Goswami, P. 2007. Reduction in Spatial and Temporal Extent of Monsoon rainfall, *Geophy Res Lett*, Vol 34, L 23704 doi:10.1029/ 2007GL031613, Dec, 2007

Rao, G.S.L.H.V.P. 1982. Rainfall and coconut yield in the Pilicode region, North Kerala. *PLACROSYM V.* Proceedings of the Fifth Symposium on Plantation Crops, Indian Society for Plantation Crops, Kasaragod, pp. 388-393

Rao, G.S.L.H.V.P. 1985. Drought and coconut palm. *Indian Cocon. J.* 15:3-6

Rao, G.S.L.H.V.P. 1986. Effect of drought on coconut production. *Indian cocon. J.* 17 (8): 11-12

Rao, G.S.L.H.V.P. 1988. Agrometeorology of coconut. *Six Decades of Coconut Research.* (eds. Aravindakshan, M., Nair, R.R. and Wahid, P.A.). Kerala Agricultural University, Thrissur, pp.81-93

Rao, G.S.L.H.V.P. 2002. Climate and cashew. Kerala Agricultural University. P. 100

Rao, G.S.L.H.V.P. 2008. Agricultural Meteorology. PHI Learning (Pvt) limited, New Delhi. 364p

Rao, G.S.L.H.V.P. and Nair, R.R. 1986. Influence of weather on nut development of coconut. *J. plantation crops* 16:469-473

Rao, G.S.L.H.V.P. and Nair, R.R. 1988. Vertical profiles of air temperature and vapour pressure in coconut gardens and open space. *Agrometeorology of Plantation Crops.* Proceedings of the national seminar (eds. Rao, G.S.L.H.V.P. and Nair, R.R.) March 12-13, 1987, Kerala Agricultural University,Thrissur, pp.63-69

Rao, G.S.L.H.V.P., Gopakumar, C.S. and Sebastian, S. 1993. Effect of drought on nut yield in different yield groups of west coast tall. *J. plantation crops* 21:25-28

Rao, G.S.L.H.V.P., Sebastian, S. and Subash, N. 1995. Solar and net radiation profiles in coconut garden in humid climates. *Indian Cocon. J.* 25: 2-5

Rao, G.S.L.H.V.P. and Subhash, N. 1996. Nut yield estimation in coconut using agroclimatic indices. In. proceeding of National Symposium on Drought Management in Plantation Crops, CWRDM, Kozhikode, pp. 1-9

Rao, G.S.L.H.V.P., Subash, N., Gopakumar, C.S. and Sebastian, S. 1997. Impact of drought on plantation crops in Kasaragod District. In: Proceedings of the 9th Swadeshi Science Congress. CPCRI, Kasaragod, November, pp. 62-68

Rao, G.S.L.H.V.P., Krishnakumar, K.N. and Tony, X. 1999. Forecasting coconut production of Kerala based on agroclimatic indices. In. proceeding of Eleventh Kerala Science Congress, February-March, Kasaragod, pp. 284-286

Rao, G.S.L.H.V.P., Krishnakumar, K.N., Gopakumar, C.S. and Sudheesh, M.V. 2005. All - India Drought of monsoon 2002 - is it relevant to Kerala (ed. Rao, G.S.L.H.V.P). In. proceedings of the brain storming session held at Kerala Agricultural University, Thrissur, 3rd March, 2003, pp3-5

Rao, G.S.L.H.V.P., Ram Mohan, H.S., Gopakumar, C.S and Krishnakumar, K.N. 2008. Climate Change and cropping systems over Kerala in the humid tropics. *J. Agrometeorol.*, special issue - Part 2: 286-291

Rao, G.S.L.H.V.P., Rao, G.G.S.N and Rao, V.U.M. 2010. Climate Change and Agriculture over India. PHI Learning (Pvt) limited, New Delhi. *328p*

Rao, K.N., Jagannathan, P. 1963. Climate change in India -1. In Proceedings of Symposium on changes in climate, Rome, UNESCO and WHO 49-66

Ratnam J. V., Sikka, D. R., Kaginalkar, A., Amitkesarkar, N., Jyothi, S. and Banerjee, S. 2007. Experimental seasonal forecast of monsoon 2005 using T170L42 AGCM on PARAM Padma. *Pure Appl. Geophys.* 164: 1641–1665

Ratnambal, M.J., Arunachalam, V. and Krishnan, M. 2003. Floral biology of some coconut accessions. *J .plantation crops* 31(1):14-22

Ravindranath, N.H., Joshi, N.V., Sukumar, R. and Saxena, A. 2006. Impact of climatechange on forests in India. *Curr. Sci.* 90: 354-361.

Rethinam, P. 1987. Management of drought situation in coconut plantation. *Indian Cocon. J.* 18: 3-5

Reynolds, S. G. 1979. A simple method for prediction of coconut yields. *Philippines journal of Coconut Studies* 4 (3): 41-44

Sakamoto C, Achutuni, R and Steyaert, L. 1984. Development of Agroclimatic/crop condition index assessment models. Prepared by NOAA/NESDIS/ASSC in co-operation with Atmospheric Science Department, University of Missouri

Salter, P. J. and Goode, J.E. 1967. *Crop Response to Water at Different Stages of Growth. Research Review No.2.* Common wealth Agricultural Bureau, England, p. 246

Samanta, M.K., Chattopadhyay, N., Hore, J.K. and Alam, K. 2009. Influence of weather factors on the floral characteristics of coconut. *J.plantation crops* 37(1):67-69

Sampson, H.C. 1923. *The Coconut Palm*. John Balesons, Danielssons Limited, London. p.320

Saraswathi, P. and Mathew, T.P. 1988. Forecasting coconut yield using monthly distribution of rainfall. In *Agrometeqrology of Plantation Crops (Proceedings of the National Seminar),* 138-143 (eds. Rao, G.S.L.H.V and Nair, R.R). Mannuthy, India: Kerala Agricultural University Press

Sen, A.K., and Sinha, Ray. K.C. 1997. Recent trends in drought affected areas in India. Presented at International Symposium on Tropical Meteorology, In.TROPMET-1997 at IIT, New Delhi

Shylaraj, K.S., Bindu, M., Gopakumar, K. and Gopimany, R. 1991. Comparing Komadan coconut type with West Coast Tall. *Coconut Breeding and Management* (eds. Silas, E.G., Aravindakshan, M. and Jose, A.I.). Proceedings of National Symposium on Coconut Breeding and Management, 1988. Kerala Agricultural University, Thrissur, pp.106-108

Sikka, D.R., 1999. Monsoon droughts, Joint COLA/CARE Tech. Rep. No. 2, 269

Sims, C.A. 1980. Macroeconomics and Reality, Econometrica, 48: 1-48

Singh, N and Sontakke, N.A. 1999. On the variability and prediction of rainfall in the post - monsoon season over India. *Int. J. of Climatol.* 19: 309-339

Sinha Ray, K.C. and Shewale, M.P. 2001. Probability of occurrence of drought in various subdivisions of India, *Mausam*, 52(3): 541-546

Soman, M.R., Krishnakumar, K., Singh, N. 1988. Decreasing trend in the rainfall of Kerala . *Curr. Sci*. 57: 7-12

Sreelatha, P.C. and Kumaran, K. 1991. Seasonal variation in floral characters of T x COD coconut hybrids. *Coconut Breeding and Management* (eds. Silas, E.G., Aravindakshan, M. and Jose, A.I.). Proceedings of National Symposium on Coconut Breeding and Management, 1988. Kerala Agricultural University, Thrissur, pp.89-93

Srivatsava, H.N., Dewan, B.N., Dikshit, S.K, Prakasa Rao, G.S., Singh, S.S., Rao, K.R. 1992. Decadal trends in climate over India. *Mausam,* 43: 7-20

Snedecor, G.W. and Cochran, W.G. 1983. Statistical Methods (7th edn), Iowa State University Press, Ames

Subrahmanyam, V.P. 1982. Water balance and application with special reference of India. Andhra University, Waltair , No.173: pp.102

Subrahmanyam, V.P. and Subramaniam, A.R. 1964. Application of water balance concept for a climatic study of drought in south India. Indian Journal of Meteorology and Geophysics,15: 393-402

Sudhakara, K. 1990. Button shedding and premature nutfall in coconut. *J. plantation crops* 18(2): 66-77

Sudhakara, K. 1991. Button shedding and premature nutfall in coconut. *Indian Cocon. J* . September 13-18

Sumith, H.W.S.D. 1985. A methodology for estimating coconut production. In report of FAO Project No. Es: TCP/SRL/2309 (T), PP 33-41

Thampan, P.K.1981. *Handbook on Coconut Palm.* Oxford and IBH publishing Co., New Delhi, p.375

Thampan, P.K. 1982. *The Coconut Palm and its Products.* Oxford and IBH publishing Co., New Delhi, p.311

Thapliyal, V., Kulshrestha, S.M. 1991. Climate changes and trends over India. *Mausam* 42: 333-338

Thornthwaite, C.W. 1948. An approach towards a rational classification of climate. *The Geographical Rev.* 38: 55-94

Thornthwaite, C.W. and Mather, J.R. 1955. The water balance. Publication in climatology, Drexel Institute of Technology, Ceterton, N J, 8 (1): pp.104

Tyson, P.D., Dyer, T.G and Namerse, M.N. 1975. Secular changes in South African rainfall:1880 to 1972. Quart. J. Roy. Meteor. Soc. 101: 817-833

Vanaja.T. and. Amma, J.S. 2002. Seasonal variation in palm characters of WCT and Komadan coconut types. *Indian Cocon.J*. 33:13-15

Varghese, A. and Kunju, M.U. 1988. Influence of weather on the yield of coconut in the backwater areas of Kuttanad. *Agrometeorology of Plantation Crops*. (eds. Rao, G.S.L.H.V.P. and Nair, R.R.). Proceedings of the National Seminar, March 12-13, 1987. Kerala Agricultural University, Thrissur, pp.131-133

Venketesan C., Raskar, S. D., Tambe, S. S., Kulkarni, B. D. and Keshavamurty, R. N. 1997. Prediction of all India summer monsoon rainfall using error - back - propagation neural networks. *Meteorol. Atmos. Phys.* 62: 225-240

Vijayakumar, K., Nambiar, P. T. N., Jacob Mathew, C. H., Amaranath, C. H. and Balakrishnan, T. K. 1988. Forecasting of yield in coconut by using weather variables. *J Plantation Crops (Supplement)* 16: 463-468

Vijayakumar, K., Mathew, J., Amarnath, C.H., Nambiar, P.T.N., Jose, C.T. and Balakrishnan, T.K. 1988. Influence of weather on coconut yield. *Agrometeorology of Plantation Crops*. (eds. Rao, G.S.L.H.V.P. and Nair, R.R.). Proceedings of the National Seminar, March 12-13, 1987. Kerala Agricultural University, pp.124-132

Vijayaraghavan, H., Raveendran,T.S. and Ramanathan,T. 1988. Influence of weather factors on yield of rainfed coconut. *Indian Cocon. J*. 18:7-9

Vijayaraghvan, H., Raveendran, T.S. and Ramanathan, T. 1993. Seasonal variation in the spathe production of spathes in certain coconut hybrids and their parents. *Indian Cocon. J.* 24:9-11

Wickremasurya, C.A. 1968. Some observation on effect of photoperiod on the flowering behaviour of coconut palm. *Ceylon Cocon. Q*. 19:152-160

World Meteorological organization. 1966. Climate Change. WMO Tech. Note. No.79.WMO No.195, TP-100, 80pp

Appendix I

Research articles published in national and international journals

Journal of Agrometeorology (Special issue - Part 2): 286-291 (2008)

Climate change and cropping systems over Kerala in the Humid Tropics

G.S.L.H.V PRASADA RAO, H.S RAM MOHAN[1], C.S GOPAKUMAR[1] and K.N RISHNAKUMAR[1]

Centre for Climate Change Research,

Kerala Agricultural University, Vellanikkara, Thrissur- 680656

kauagmet@yahoo.co.in

Department of Atmospheric Sciences, CUSAT, Cochin – 682016

ABSTRACT

There was a decline in southwest monsoon and annual rainfall since 1951 onwards at the rate of 5.2mm/year and 5.6 mm/year, respectively. The climate over Kerala also shifted from wetness to dryness within the humid climate (B_4 to B_3) during the study period from 1951 to 2007. There was a shift in cropping systems across the State of Kerala as the index of foodgrain crops was declining while increasing the index of non-foodgrain crops. Unlike in seasonal crops, the effects of climate change on long term basis in terms of global warming may not be seen on crops like coconut, rubber and arecanut as they are grown under tolerable limits of surface air temperature. However, the occurrence of floods and droughts as evident in 2007 (floods due to excess monsoon rainfall by 41% against normal) and summer 2004 (drought due to no significant rainfall from November, 2003 to April 2004), is likely to increase in ensuing decades as projected and crop losses are expected. The unusual summer rains in 2008 devastated the paddy crop in Kuttanad and Kole lands of Thrissur. In contrast, it was beneficial to crops like cardamom, coconut and arecanut. The thermosensitive crops like cocoa, black pepper, coffee, cardamom and tea may need attention as temperature range is likely to increase and rainfall is likely to decline in addition to deforestation as these crops are grown under the influence of typical forest -agro-ecosystems. Deforestation, shift in cropping systems, decline in wetlands and depletion of surface and groundwater resources may aggravate the ill effects of floods and droughts on all the crops. Hence, there is an urgent need for pro-active measures on short-term and long- term basis against the climate change risks for sustenance of crop production both in terms of quantity ands quality.

Key words: Climate change, climate projection, change in cropping systems, thermosensitve crops, food security

Climate change/variability is the concern worldwide and nationwide too. The weather abnormalities like floods and droughts and heat and cold waves are frequent in recent years as the top twelve warmest years took place since 1995 onwards. The year 1998 was the warmest year and known as the weather related disaster year globally. The heat wave during summer 2003 was a havoc in the European Union and 2007 was the warmest winter in the Northern Hemisphere. It is reported that during the past 100 years, global mean surface air temperatures have risen by 0.74°C and it is projected to rise by 1 to 3°C during this century. Hingane *et. al.,* (1985) reported that the Country-wide annual surface air temperature has increased by 0.4°C/100 years in 20th century but the rate of increase slowed down in the recent three decades. The monsoon seasonal rainfall was in decreasing trend over east Madhya Pradesh and adjoining areas, North-east India and parts of Gujarat and Kerala (Kumar *et. al.,* 2002). At regional level, the temperature and rainfall trends differ significantly and studies are scant in this direction. An increase of 0.5°C in the mean surface air temperature was also noticed since 1960s over the State of Kerala and 1987 was the warmest year. Rainfall in recent years was declining. However, the monsoon rainfall was excess in 2007 and unusual summer rains were received much ahead in 2008. 1987, 2002 and 2008 were typical monsoon years during which rainfall distribution was different when compared to the normal monsoon behaviour. The distribution of rainfall is such that it may lead to frequent floods during monsoon or drought during summer. This phenomenon appears to be more frequent and it can be attributed to global warming due to man- made interventions. It will result in severe consequences on various sectors and it is more so in agricultural sector including food security and food prices. Keeping the above in view, an attempt was made

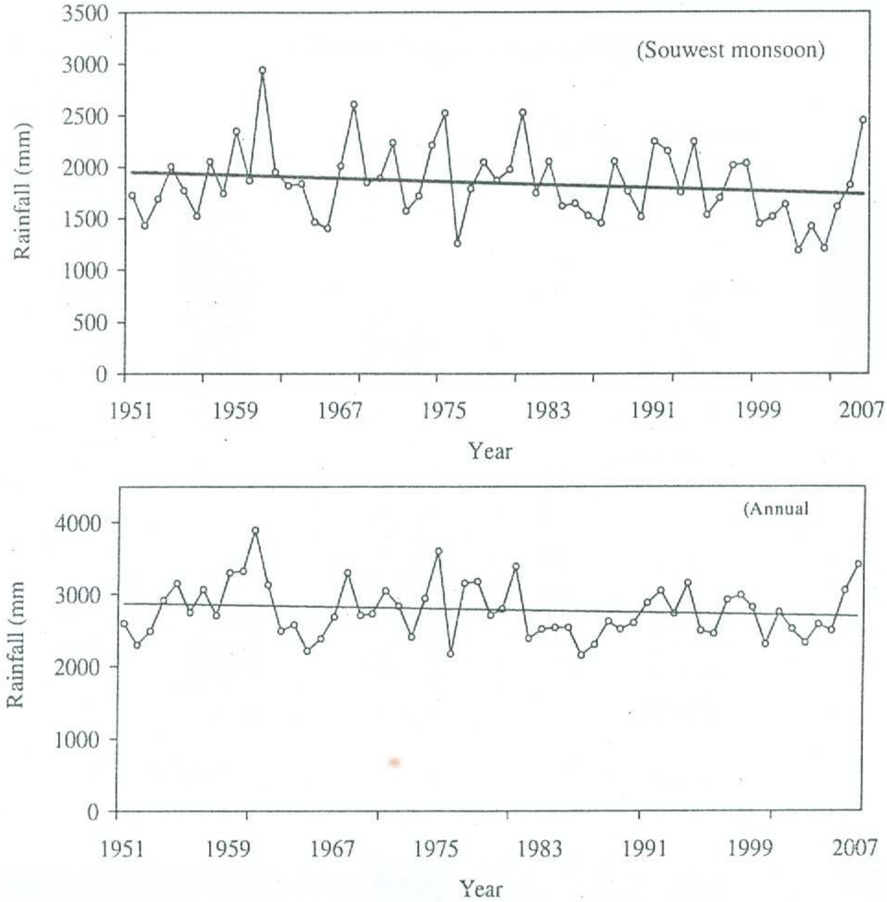


Fig 1: Rainfall (mm) over Kerala from 1951-2007

to analyze rainfall trends, climate shifts and shifts in cropping systems over Kerala.

MATERIALS AND METHODS

Area, production and productivity of major crops grown in Kerala were collected from the 'Economic Review' published by Kerala State Planning Board for the year from 1952-53 to 2006-07 to work out the trends in area, production and productivity of these crops. Monthly rainfall for the study period was collected from the IITM publication entitled "Monthly and seasonal rainfall series for all India homogenous regional and meteorological sub divisions: 1871 – 1994" (Parthasarathy *et al.*, 1995). From 1995 to 2007, daily rainfall data published by the India Meteorological Department, Trivandrum were utilized. Rainfall trends and climate shifts were worked out and analyzed the impact of climate on cropping systems over Kerala.

The moisture index was used as an index for working out climate shifts over Kerala. Yearly water balance for the State as a whole were computed for a period of 137 years (1871-2007) using the Thronthwaite and Mather (1955) book - keeping water balance procedure, given by Subrahmanyam (1982). The monthly Aridity Index (Ia), Moisture Index (Im) and humidity Index (Ih) were computed from 1851 to 2007 using the formula given below:

$Ia = WD/PE \times 100$ $Ih = WS/PE \times 100$ $Im = Ih - Ia$

Where, AE-Actual evapotranspiration, PE-Potential Evapotranspiration, WS-Water Surplus, WD-Water deficit.

RESULTS AND DISCUSSION

The annual rainfall showed a declining trend over a period of 57 years from 1951 to 2007 over Kerala.

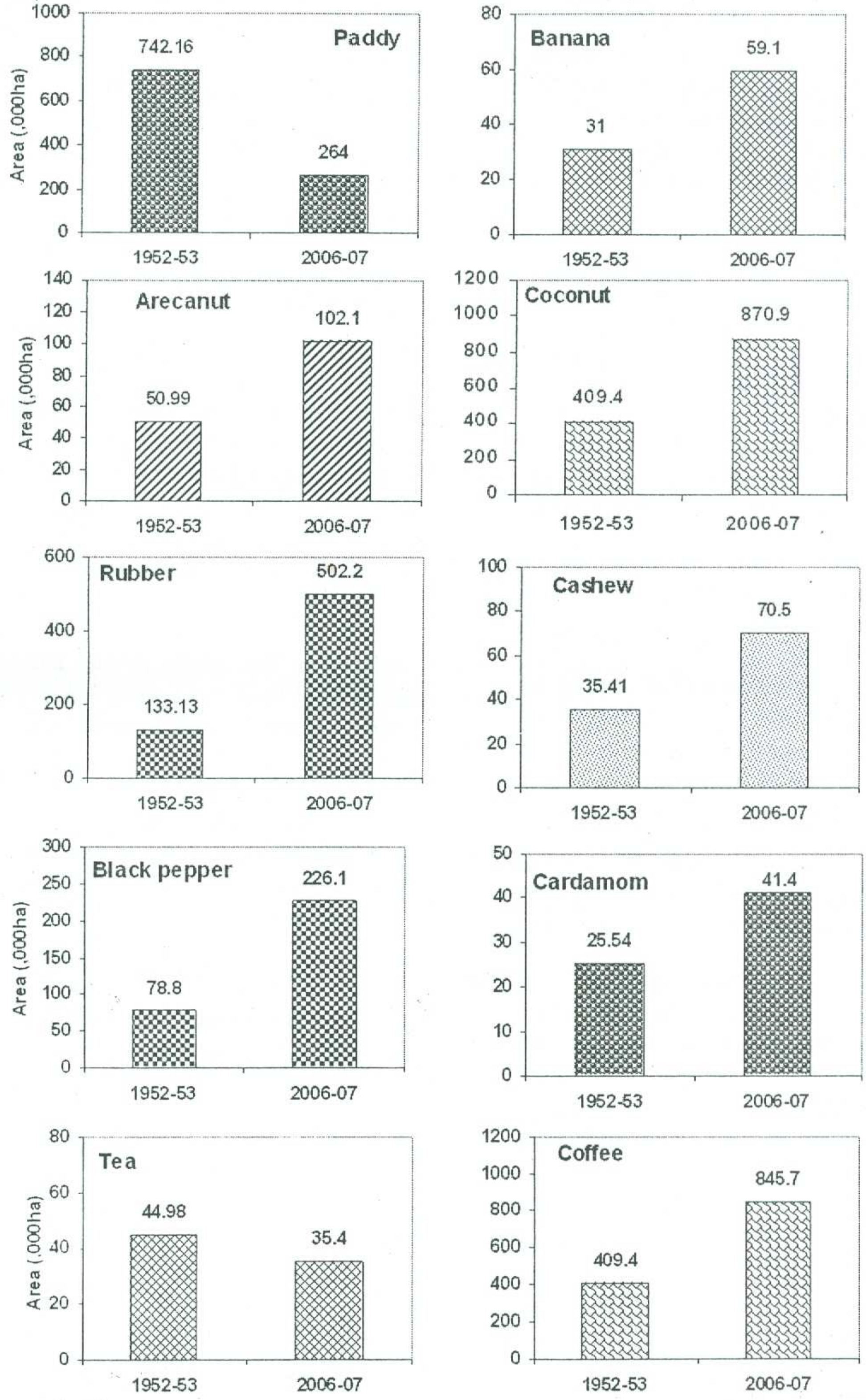


Fig. 4: Climate change and cropping systems across the State of Kerala

Kerala while the quality and quantity of black pepper suffered in Idukki District. In the case of coconut, the total coconut production of the State during the decade of 1981-90 was relatively low due to more number of summer droughts experienced in the State. The summer drought in 1983, 1989 and 2004 adversely affected the total coconut production during the following year to a large extent at the field and the State level. The cocoa yield in 2004 was less by 39% due to increase in temperature during summer by 1-3°C (February - March, 2004). It was true in the case of cardamom also. The crops like cardamom, coffee and tea need attention under a threat of climate change (temperature range is likely to increase and deforestation is alarming) as these crops are grown under the influence of typical forest -agro- ecosystems. It reveals that crop losses or gains are subjected to climate variability rather than climate change. However, crop simulation models indicate decline in yield across the Country due to increase in temperature and CO_2 in the atmosphere. Interestingly in the case of coconut, such trend is not seen over Kerala through the coconut gardens in non-traditional areas (Karnataka, Tamil Nadu and Andhra Pradesh) are likely to suffer due to global warming. Similar may be the case in rubber and in arecanut. However, all the model projections need to be tested and revalidated from time to time to obtain realistic crop projections. These studies need intensive field test for confirmation as model output always overestimates. Generation of database and research efforts in this direction are the need of the hour to understand the climate change and its relationships with cropping systems, especially in plantation sector.

REFERENCES

Hingane, L. S., Rupakumar, K. and Ramana Murthy, B. V. (1985). Long term Trends of surface air temperature in India. International J. *Climatol.*, 5: 521-528.

Kumar, K .R., Kumar, K. K., Ashrit, R. G., Patwardhan, S. K. and Pant, G. B. (2002). Climate change in India: Observation and Model Projections. Climate change and India-Issues, Concern and Opportunities (eds. Shukla, P.R., Sharma, K.S. and Ramana, P.V.). Tata McGraw-Hill Publishing Company Limited, New Delhi, pp 24-75.

Krishnakumar, K.N., Prasada Rao, G.S.L.H.V.P and Gopakumar, C.S.(2008). Climate change at selected locations in the Kerala State, India. *Agrometeorol.,* 10(1): 59-64

Parthasarathy, B., Munot, A.A and Kothawale, D.R. (1995). Monthly and seasonal rainfall series for all India homogeneous regions and meteorological sub-divisions:1871-1994. Contributions from IITM, Pune, India. Research Report No. RR-065. 113 p.

Rao, G.S.L.H.V.P., Alexander, D., Krishnakumar, K.N and Gopakumar C.S. (2008). Impact of climate change on plantation crops over the humid tropics of Kerala. In "Climate Change and Agriculture over India". (Eds. G.S.L.H.V Prasada Rao, G.G.S.N.Rao, V.U.M. Rao and Y.S.Ramakrishna).pp.49-78. Kerala Agricultural University, Thrissur, Kerala, India

Subrahmaniam, V.P. (1982). Water balance and applications with special reference of India. Andhra University, Waltair, No.173: pp.102

Thornthwaite, C.W. and Mather, J.R. (1955). The water balance publication in climatology., Dexel Institute of Technology, Centerton, NJ 8(1). pp.104

Atmospheric Environment 43 (2009) 1940–1944

Contents lists available at ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Rainfall trends in twentieth century over Kerala, India

K.N Krishnakumar*, G.S.L.H.V. Prasada Rao, C.S Gopakumar

Dept. of Agricultural Meteorology, College of Horticulture, Kerala Agricultural University, Vellanikkara, Thrissur-680 656, Kerala, India

ARTICLE INFO

Article history:
Received 10 July 2008
Received in revised form
26 December 2008
Accepted 28 December 2008

Keywords:
Man-Kendall rank statistics
Trends
Coefficient of variation
Southwest monsoon

ABSTRACT

Attempts were made to study temporal variation in monthly, seasonal and annual rainfall over Kerala, India, during the period from 1871 to 2005. Longterm changes in rainfall determined by Man-Kendall rank statistics and linear trend. The analysis revealed significant decrease in southwest monsoon rainfall while increase in post-monsoon season over the State of Kerala which is popularly known as the "Gateway of summer monsoon". Rainfall during winter and summer seasons showed insignificant increasing trend. Rainfall during June and July showed significant decreasing trend while increasing trend in January, February and April. Hydel power generation and water availability during summer months are the concern in the State due to rainfall decline in June and July, which are the rainiest months. At the same time, majority of plantation crops are likely to benefit due to increase in rainfall during the post-monsoon season if they are stable and prolonged.

1. Introduction

Several researchers studied on variability and trends in rainfall across the world. Nicholson (2000) observed that one of the most important contrasts in rainfall is the multi-decadal persistence of anomalies over northern Africa. Nicholson and Grist (2001) had identified several changes in the general atmospheric circulation that have accompanied the shift to drier conditions in West African Sahel. Rainfall variability in southern Spain on decadal to centennial time scales were studied by Rodrigo et al. (2000). Rotstayn and Lohmann (2002) showed a prominent feature is the drying of the Sahel in North Africa and suggest that the indirect effects of anthropogenic sulfate may have contributed to the Sahelian drying trend. Akinremi et al. (2001) reported that there has been a significant increase in rainfall and its events during the most recent 40-year period (1956–95). Increase in annual rainfall was 51 mm, or about 16% of the 40-year mean, while the number of rainfall events increased by 17, or about 29% on the Canadian prairies. Murphy and Timbal (2007) reported that most of the rainfall decline (61%) has occurred in Autumn (March–May) in southeastern Australia. A similar rainfall decline occurred in the southwest of Western Australia around 1970 that has many common features with the southeastern Australia decline. Nicholls and Lavery (2006) reported that summer rainfall over much of eastern Australia increased abruptly around 1950s. In the Southwest of the continent, majority of stations recorded a smoother trend to lower winter rainfall, although there is a small area with increased rainfall.

Attempts have been made to study trends in annul and seasonal rainfall over India since the beginning of the last century. Long term trends of Indian monsoon rainfall for the Country as well as for smaller subdivisions were studied by Pramanik and Jagannathan (1954), Parthasarathy and Dhar (1978), Parthasarathy (1984), Mooley and Parthasarathy (1983), Parthasarathy et al. (1993). All-India spatial scale showed treadles and random nature for a long period of time (Mooley and Parthasarathy, 1984). Rao and Jagannathan (1963), Thapliyal and Kulshrestha (1991) and Srivatsava et al. (1992) also reported that All-India southwest monsoon/annual rainfall observed no significant trend. Long term trend in small spatial scale was reported by Koteswaram and Alvi (1969), Jagannathan and Parthasarathy (1973), Jagannathan and Bhalme (1973), Naidu et al. (1999) and Singh and Sontakke (1999). Rupa Kumar et al. (1992) have found significant increasing trend in monsoon rainfall along the West Coast, north Andhra Pradesh and northwest India while significant decreasing trends over Madhya Pradesh and adjoining area, northeast India and parts of Gujarat and Kerala. Guhathakurta and Rajeevan (2007) observed decreasing trend in almost all subdivisions except for subdivisions in Himachal Pradesh, Jharkhand and Nagaland, Manipur, Mizoram and Tripura during winter. During pre-monsoon season, rainfall is decreasing over most parts of the Central India, Gujarat region, West Madhya Pradesh, East Madhya Pradesh, Vidarbha, Chattisgrath and Jharkhand. Rainfall is significantly increasing over Sourashtra and Kutch, Marathwada and Rayalseema during post-monsoon season. Annual and southwest monsoon rainfall showed

* Corresponding author. Tel./fax: +9104872371931.
E-mail address: krishna_kn2000@yahoo.com (K.N Krishnakumar).

1352-2310/$ – see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.atmosenv.2008.12.053

significant decreasing trend over Chattisgrah, Jharkhand and Kerala. All these studies reveal that there is no similarity in rainfall trends at the regional level.

Kerala State is located between 8°15′N and 12°50′N latitudes and between 74°50′E and 77°30′E longitudes (Fig. 1). The State of Kerala is popularly known as the "Gateway of summer monsoon" over India. It is a strip of land running almost in North–South direction and is situated between the West Arabian sea on the West and the ranges of Western Ghats and Nilgiri hills on the East both running parallel to each other. From the Western Ghats, the State undulates to the West and presents a series of hills and valleys intersected by numerous rivers. On extreme West, the State is more or less flat. These characteristics demarcate the State into three natural regions viz., the eastern high lands, the hilly midlands and western low lands. The changes in the geographical and topographical features due to man-made interventions are likely to influence atmospheric circulation altitudinally to a large extent. It may be one of the reasons in recent times for uncertainties in monsoon variability and rainfall distribution over Kerala. Ananthakrishnan and Soman (1988, 1989) studied the onset of monsoon and monsoon rainfall in detail over Kerala utilising the data up to 1980. Soman et al. (1988) reported that annual rainfall over Kerala showed significant decreasing trend. In view of the importance of variability in rainfall, as indicated above, it would be of interest to study the long-term variation of monthly, annual and seasonal rainfall over Kerala which is known as the "Gateway of summer monsoon" over India.

2. Data and methodology

The source of monthly rainfall (mm) over Kerala from 1871 to 1994 is from the IITM publication entitled "Monthly and seasonal rainfall series for all-India homogeneous regions and meteorological subdivisions: 1871–1994" (Parthasarathy et al., 1995). Monthly, seasonal and annul rainfall series of Kerala State were constructed using monthly rainfall data of fixed network of 10 raingauge stations. On an average, there is one raingauge station for every 3886.4 sq. km area. From 1995 to 2005, the monthly rainfall data were collected from the daily weather reports published by the IMD, Trivandrum. From the Basic monthly rainfall data, monthly mean, seasonal rainfall, Standard Deviation (SD) and Coefficient of Variation (C.V.) and 75 per cent rainfall probability were computed monthly and season-wise viz., Pre-monsoon (March–May), Southwest monsoon (June–September), Post-monsoon (October–November) and Winter (December–February) that are depicted in Table 1. The data were subjected to 11-year-running mean to find out long term trends. A linear trend line was added to the series for simplify the trends. To support trends in annual and seasonal rainfall, decade-wise shifts in rainfall over Kerala were also analysed from the period 1871 to 2005. Temporal changes in the seasonal and annual rainfall were also analysed by Man-Kendall rank statistics (t) to confirm the significance of the observed trend. The values of t were used as the basis of a significant test by comparing it with

$$T_t = 0 \pm t_g\sqrt{4N + 10/9N(N-1)}$$

where t_g is the desired probability point of the Gaussian normal distribution. In the present study, t_g at 0.01 and 0.05 points were considered for comparison. Apart from this, the linear trend fitted to the data was also tested with t test to verify results obtained by Man-Kendall test.

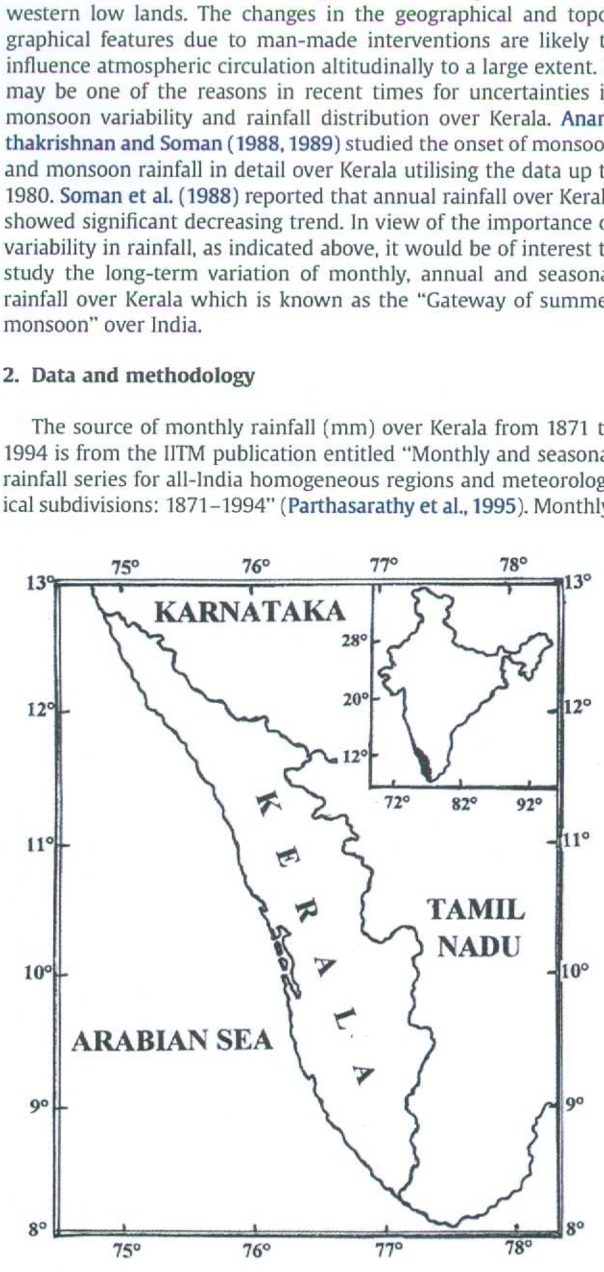


Fig. 1. Location map of Kerala.

3. Rainfall features

Rainfall characteristics of Kerala are reported in Table 1. The annual normal rainfall over Kerala from 1871 to 2005 is 2817 mm with a standard deviation of 406 mm. The dependable annual rainfall at 75 per cent level is 2493 mm and the dependable seasonal rainfall at 75 per cent for pre-monsoon, southwest monsoon, post-monsoon and winter season is 269.3 mm, 1624.2 mm, 341.0 mm and 30.3 mm, respectively. The coefficient of variation of annual rainfall is 14.4%, indicating that it is highly stable. Rainfall during June is the highest (684 mm) and contributes to 24.3% of annual rainfall (2817 mm), followed by July (22.4%). Rainfall in August and September contributes to 13.2% and 8.0% of

Table 1
Monthly and seasonal means of rainfall (mm) over Kerala from 1871 to 2005.

Month	Rainfall (mm)				
	Normal	Standard deviation	CV (%)	75% probability	Percentage contribution to annual rainfall
January	12	17	146.1	0.4	0.4
February	17	19	115.4	2.9	0.6
March	36	28	78.5	15.5	1.3
April	112	52	46.5	75.3	4.0
May	246	159	64.6	131.1	8.7
June	684	194	28.4	576.3	24.3
July	632	209	33.2	502.8	22.4
August	373	157	42.0	270.5	13.2
September	224	122	54.7	134.7	8.0
October	288	108	37.5	204.5	10.2
November	156	85	54.4	91.5	5.5
December	38	39	102.1	11.3	1.3
Annual (mm)	2817	406	14.4	2493.0	100
Pre-monsoon	393.7	163.5	41.5	269.3	14.0
Southwest	1913.5	377.7	19.7	1624.2	67.9
Post-monsoon	444.1	138.4	31.2	341.0	15.8
Winter	65.3	46.7	71.4	30.3	2.3

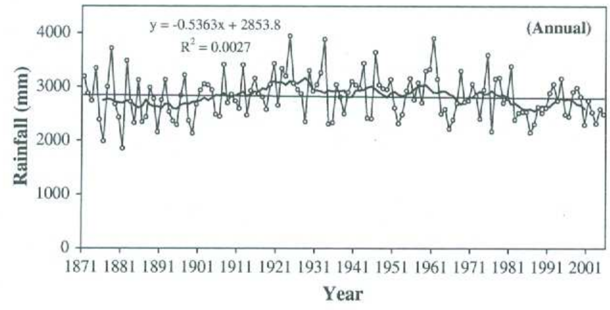


Fig. 2. Annual rainfall trends over Kerala from 1871 to 2005.

the annual rainfall, respectively. Rainfall in January is the least (12.0 mm) and contributes only 0.4% to the annul rainfall. The coefficient of variation is also the highest during January (146.1%), followed by February (115.4%) and December (102.1%) and the least during the high rainfall months of June (28.4%) and July (33.2%). Rainfall during the southwest monsoon (June–September) contributes 67.9% of the annul rainfall. The contribution of pre-monsoon (March–May), post-monsoon and winter rainfall to the annual is 14.0, 15.8 and 2.3, respectively. The seasonal rainfall during monsoon (June–September) is dependable as the coefficient of variation is 19.7%. At the same time, rainfall during winter is undependable as the coefficient of variation is very high (71.4%), varying between 102.1% in December and 146.1% in January.

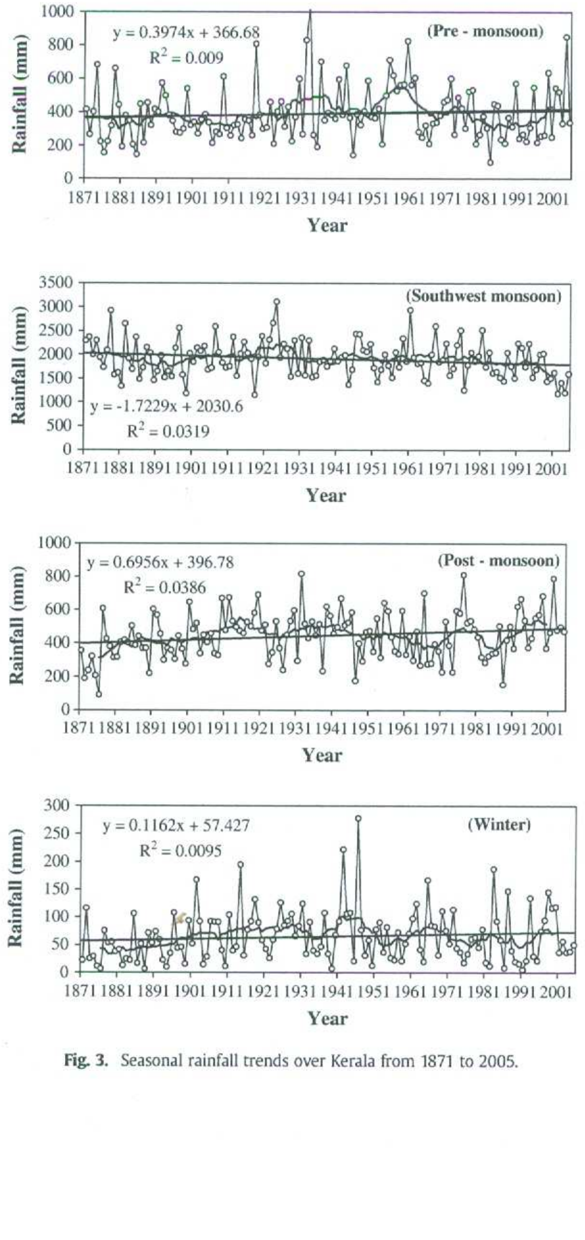


Fig. 3. Seasonal rainfall trends over Kerala from 1871 to 2005.

Table 2
Linear equations and their significance tested by *t*-test.

Rainfall	Linear equations	Calculated *t*
Annul	$y = -0.5363x + 2853.8$	0.6006
Pre-monsoon	$y = 0.3974x + 366.68$	1.0990
Southwest monsoon	$y = -1.7229x + 2030.6$	2.0934**
Post-monsoon	$y = 0.6956x + 396.78$	2.3108**
Winter	$y = 0.1162x + 57.427$	1.1294

*Significant at 0.05 level, **significant at 0.01 level.

4. Annual rainfall trends

The mean annual rainfall over Kerala showed a long term insignificant declining trend. However, the declining trend in annual rainfall was significant if the annual rainfall considered from 1951 onwards. The annual rainfall in recent years from 1999 to 2005 was less by 9.8%. A relatively wet period (excess rainfall) was seen in earlier decades from 1900 to 1980 (Fig. 2). A decrease of 72.4 mm only was noticed during the study period of 135 years as against the normal rainfall of 2817 mm.

5. Seasonal rainfall trends

5.1. Pre-monsoon (March–May)

A decline in pre-monsoon rainfall was noticed up to mid 1920 and then increased up to later 1930s (Fig. 3). There was an overall insignificant increase during the study period of 135 years. An increase of 53.7 mm was noticed as against the normal (393.7 mm).

5.2. Southwest monsoon (June–September)

The southwest monsoon rainfall was more from 1901 to 1930 against the normal while decreasing from 1981 to 2005. The Man-Kendall test statistics (−2.0582) indicates that the decrease in southwest monsoon rainfall is significant at 0.01 level. Overall, a decline of 232.6 mm was noticed during the study period of 135

Table 3
Man-Kendall rank statistics of monthly and seasonal rainfall over Kerala.

Month	Rainfall (mm)
January	**2.1438****
February	1.7961*
March	0.9454
April	1.7443*
May	0.3139
June	**−2.5660****
July	−1.7177*
August	0.2771
September	0.7342
October	1.4457
November	1.5351
December	−0.2891
Annual (mm)	−0.6619
Pre-monsoon	0.9568
Southwest monsoon	**−2.0582****
Post-monsoon	**2.2160****
Winter	1.0082

*Significant at 0.05 level, **significant at 0.01 level.

Table 4
Monthly and seasonal contribution of rainfall (%) to annual from 1871 to 2005 over Kerala.

Month/Season	1871–1900	1901–1930	1931–1960	1961–1990	1991–2005
June	27.7	24.1	23.1	22.4	24.0
July	22.9	23.6	21.8	22.8	19.7
August	13.2	12.9	12.8	14.6	12.2
September	7.3	8.2	7.3	9.1	7.6
October	9.3	10.4	10.2	9.5	13.3
November	4.3	5.9	6.0	5.5	6.3
Pre-monsoon	13.4	12.2	16.4	13.6	14.4
Southwest monsoon	71.2	68.8	65.1	68.9	63.6
Post-monsoon	13.6	16.3	16.2	15.0	19.5
Winter	1.2	2.6	2.5	2.4	2.4

years indicating that on an average, the southwest monsoon rainfall decline was about 1.7 mm year^{-1}. In recent years, the distribution of rainfall during the season is poor and in the major water reservoirs, the water level was low on which the hydel power generation depends across the State.

5.3. Post-monsoon (October–November)

Post-monsoon rainfall depicts two epochs of high rainfall around mid 1910s and 1940s. The Man-Kendall test indicated that the seasonal rainfall during the post-monsoon is significant at 0.01 level and increasing trend was noticed. Therefore, it can be inferred that the post-monsoon rainfall was significantly increasing. Such trend was more evident since 1961 onwards. It also showed through the trend line that an increase of 93.9 mm was noticed during the study period of 135 years. The post-monsoon rainfall increasing was about 0.7 mm year^{-1} during the study period.

5.4. Winter (December–February)

The winter rainfall had an increasing tendency, which is not statistically significant. The 11-year – running – mean indicated that winter rainfall increased from 1900 to 1950. It also showed through the trend line that an increase of 15.7 mm only was noticed during the study period of 135 years. Increase in rainfall during the season is beneficial to the plantation crops. However, high variability of rainfall lead to uncertainty and the crops need assured irrigation. The *t*-test when applied (Table 2) indicated that southwest and post-monsoon rainfall trends are significant at 0.01 level.

6. Monthly rainfall trends

Behaviour of monthly rainfall has been studied for individual months by subjecting them to the Man-Kendall test. The results are presented in Table 3. It is interesting to note that rainfall in June and July showed a decreasing trend and significant at 0.01 and 0.05 level, respectively. Rainfall of August, September, October and November showed an insignificant increasing trend. Rainfall during January showed an increasing trend which is significant at 0.01 level. February and April also showed increasing trend, which is statistically significant at 0.05 level, while remaining months showed no particular significant trend. There was a decline in (27.7–22.4%) rainfall contribution of June to the annual rainfall over a period of time (Table 4). Unlike in June, the contribution of rainfall during July is stable though variations were noticed from one- and three-decadal-period to another. In contrast, the contribution of rainfall during August (13.2–14.6%) and September (7.3–9.1%) is increasing. Similar increasing trends were noticed during October and November in rainfall contribution to the annual. As a whole, the percentage rainfall contribution during the southwest monsoon was declining while increasing during pre- and post-monsoon season and winter over Kerala. The above phenomenon was more significant in recent decades. However, rainfall during the monsoon season is stable while instable in remaining months. These two contrasting phenomena in seasonal rainfall trends are the major concern across the State. Rainfall increase during January, February and April will be beneficial to majority of the plantation crops. However, cloudy weather and rain during the above months may adversely affect the fruit quality in mango, cashew and black pepper.

7. Shifts in decade-wise annual and seasonal rainfall

Decade-wise percentage departure of annual and seasonal rainfall, frequencies of excess and deficit years depicted in Table 5. The deficient or excess rainfall years are defined for those years when rainfall is less or more than the standard deviation. Pant and Rupa Kumar (1997) reported that Indian summer monsoon displays multi-decadal variations in which there is clustering of dry or wet anomalies. During the wet decade 1871–1880, there were four excess rainfall years. During the dry period of 1881–1900, three excess years and five deficit years were observed. During the next five decades of the wet period, ten excess years and two deficit years only have been found. In the dry period of 1951–2005, there were 14 deficit years and five excess years. During the period of

Table 5
Decadal mean (% departure from normal), frequency of excess and deficit rainfall years over Kerala from 1871 to 2005.

Decade	Pre-monsoon			Southwest monsoon			Post-monsoon			Winter			Annual		
	Decadel mean (% departure from normal)	Excess	Deficit	Decadel mean (% departure from normal)	Excess	Deficit	Decadel mean (% departure from normal)	Excess	Deficit	Decadel mean (% Departure from normal)	Excess	Deficit	Decadel mean (% departure from Normal)	Excess	Deficit
1871–1880	−3.4	2	3	9.1	4	0	−28.8	1	4	−33.1	1	2	0.7	2	2
1881–1890	−20.2	0	4	−1.5	2	3	−12.7	0	1	−37.1	0	3	−6.9	1	4
1891–1900	−0.1	1	0	−6.8	1	2	−8.0	1	2	−21.6	0	2	−6.6	1	4
1901–1910	−14.1	1	1	3.8	1	0	5.5	2	0	4.9	1	2	1.6	1	0
1911–1920	−8.0	1	0	1.5	2	1	23.1	2	0	33.0	2	0	4.0	2	0
1921–1930	−3.6	1	2	13.3	4	0	−1.6	1	2	17.8	1	0	8.7	3	1
1931–1940	21.9	3	1	−1.5	2	0	12.9	2	2	−9.7	1	1	3.6	2	2
1941–1950	8.3	3	1	5.3	2	1	4.0	2	2	54.5	2	1	6.6	2	1
1951–1960	35.1	5	1	−5.0	1	2	5.6	3	0	−15.0	0	0	1.7	1	1
1961–1970	−4.5	2	1	3.4	2	2	−13.2	1	4	28.6	2	1	0.1	2	2
1971–1980	4.2	1	1	0.4	1	1	11.5	2	2	−15.7	1	0	2.3	1	2
1981–1990	−13.9	1	2	−6.4	1	3	−17.4	0	2	−7.5	2	3	−9.3	1	3
1991–2000	−17.8	1	2	−2.5	0	3	17.8	3	0	17.4	4	1	−1.4	0	1
2001–2005	32.0	1	0	−26.0	0	3	22.9	1	0	−32.3	0	0	−10.1	0	1

1871–2005, the number of deficit years was more (24) than the number of excess years (19) on annual basis while excess rainfall years more than or equal to deficit rainfall years during pre-monsoon, southwest monsoon, post-monsoon and winter seasons.

8. Conclusion

An important aspect of the present study is the significant decrease in southwest monsoon rainfall while increase in post-monsoon season. Rainfall decline is more predominant in June and July but not so in August and September within the monsoon season. There was a major shift in rainfall pattern temporarily during recent years as seasonal rainfall during the southwest monsoon was declining while increasing in post-monsoon season. The decreasing trend in southwest monsoon rainfall over Kerala is supported by other researchers (Rupa Kumar et al., 1992; Guhathakurta and Rajeevan, 2007). Joseph et al. (2004) reported that the period of Intra Seasonal Oscillation of South Kerala rainfall during summer monsoon has large inter-annual variability in the range of 23–64 days. Joseph and Xavier (1999) reported that monsoon depression frequency had a strong decreasing trend during last 100 years and the frequency now is less than half of the frequency of depressions at the beginning of the twentieth century. Rajendra Kumar and Dash (2001) showed that the decadal frequency of number of depressions was decreasing in recent years. Joseph and Simon (2005) reported that the southwest monsoon current through peninsular India from surface to 1.5 km altitude between 10 and 12°N latitude had significant decreasing trend. Sathiyamoorthy (2005) and Rao et al. (2004) showed that strength of Tropical Easterly Jet Stream was decreasing in recent 5 decades. The number of monsoon depressions formed during the southwest monsoon season, strength of monsoon current and strength of Tropical Easterly Jet Stream are the important rain bearing systems during southwest monsoon season. The frequency decline of the above weather systems in recent years over peninsula may be an important reason for decrease in southwest monsoon rainfall over Kerala. In addition to this, there is a drastic change in biophysical resources of Kerala State due to man-made interventions in recent decades. It indirectly affects the physical processes between the earth-atmosphere continuum and influenced the distribution of local rainfall during winter and pre-monsoon season. There has been a two-fold increase in the tropical cyclones frequency over Bay of Bengal during November in past 122 years (Singh et al., 2001). Cyclones developed during the post-monsoon season contribute significant amount of rainfall during the season. It is a peculiar climatic feature over southern peninsula due to the influence of Bay of Bengal. Increasing the frequency of tropical cyclones during the post-monsoon season may be the one of the important reasons for increasing post-monsoon rainfall over Kerala.

References

Akinremi, O.O., McGinn, S.M., Cutforth, H.W., 2001. Seasonal and spatial patterns of rainfall trends on the Canadian prairies. Journal of Climate 14 (9), 2177–2182.

Ananthakrishnan, R., Soman, M.K., 1988. The onset of the Southwest monsoon over Kerala: 1901–1980. International Journal of Climatology 8, 283–296.

Ananthakrishnan, R., Soman, M.K., 1989. Onset dates of the Southwest monsoon over Kerala for the period 1870–1900. International Journal of Climatology 9, 321–322.

Guhathakurta, P., Rajeevan, M., 2007. Trends in the rainfall pattern over India. International Journal of Climatology 28 (11), 1453–1469. doi:10.1002/joc.1640. Available from: www.intersciences.wiley.com.

Jagannathan, P., Bhalme, H.N., 1973. Changes in pattern of distribution of southwest monsoon rainfall over India associated with sunspots. Monthly Weather Review 101, 691–700.

Jagannathan, P., Parthasarathy, B., 1973. Trends and periodicities of rainfall over India. Monthly Weather Review 101, pp. 371–375.

Joseph, P.V., Simon, Anu, 2005. Weakening trend of the southwest monsoon current through peninsular India from 1980 to the present. Current Science 89, 687–694.

Joseph, P.V., Xavier, P.K., 1999. Monsoon rainfall and frequencies of monsoon depressions and tropical cyclones of recent 100 years and an out look for the first decades of 21st Century, Meteorology beyond 2000. In: Proceedings of Indian Meteorological Society, TROPMET-99. pp. 364–371.

Joseph, P.V., Simon, Anu, Nair, Venu G., Thomas, Aype, 2004. Intra-Seasonal Oscillation (ISO) of south Kerala rainfall during the summer monsoons of 1901–1995. In: Proceedings of the Indian Academy of Sciences (Earth Planetary Sciences), vol. 113, No. 2, pp. 139–150.

Koteswaram, P., Alvi, S.M.A., 1969. Secular trends and periodicities in rainfall at west coast stations in India. Current Science 101, 371–375.

Mooley, D.A., Parthasarathy, B., 1983. Variability of Indian summer monsoon rainfall and tropical circulation features. Monthly Weather Review 111, 967–968.

Mooley, D.A., Parthasarathy, B., 1984. Fluctuations in all – India summer monsoon rainfall during 1871–1978. Climate Change 6, 287–301.

Murphy, Bradley F, Timbal, Bertrand, 2007. A review of recent climate variability and climate change in southeastern Australia. International Journal of Climatology. doi:10.1002/joc.1627 Available from: www.interscience.wiley.com.

Naidu, C.V., Srinivasa Rao, B.R., Bhaskar Rao, D.V., 1999. Climatic trends and periodicities of annual rainfall over India. Meteorological Application 6, 395–404.

Nicholls, Neville, Lavery, Beth, 2006. Australian rainfall trends during the twentieth century. International Journal of Climatology 12 (2), 153–163. doi:10.1002/joc.3370120204. Available from: www.interscience.wiley.com.

Nicholson, Sharon E., 2000. The nature of rainfall variability over Africa on time scales of decades to millennia. Global and Planetary Change 26 (1–3), 137–158.

Nicholson, S.E., Grist, J.P., 2001. A conceptual model for understanding rainfall variability in the West African Sahel on interannual and interdecadal timescales. International Journal of Climatology 21 (14), 1733–1757. doi:10.1002/joc.648. Available from: www.interscience.wiley.com.

Pant, G.B., Rupa Kumar, K., 1997. Climate of South Asia. John Wiley and sons, Chichester, 320 pp.

Parthasarathy, B., 1984. Inter annual and long term variability of Indian summer monsoon rainfall. In: Proceedings of the Indian Academy of Sciences (Earth Planetary Sciences), vol. 93, pp. 371–385.

Parthasarathy, B., Dhar, O.N., 1978. Climate Fluctuations Over Indian Region – Rainfall: a Review, vol. 31. Indian Institute of Tropical Meteorology, Pune. Research Report No. RR-025.

Parthasarathy, B., Rupakumar, K., Munot, A.A., 1993. Homogeneous Indian monsoon rainfall: variability and prediction. In: Proceedings of the Indian Academy of Sciences (Earth Planetary Sciences), vol. 102, pp. 121–155.

Parthasarathy, B., Munot, A.A., Kothawale, D.R., 1995. Monthly and Seasonal Rainfall Series for All India Homogeneous Regions and Meteorological Sub-divisions: 1871–1994. IITM, Pune, India, Research Report No. RR-065, p. 113.

Pramanik, S.K., Jagannathan, P., 1954. Climate change in India – 1: rainfall. Indian Journal of Meteorology Geophysics 4, 291–309.

Rajendra Kumar, J., Dash, S.K., 2001. Interdecadal variations of characteristics of monsoon disturbances and their epochal relationships with rainfall and other tropical features. International Journal of Climatology 21 (6), 759–771.

Rao, K.N., Jagannathan, P., 1963. Climate change in India – 1. In: Proceedings of Symposium on Changes in Climate. UNESCO and WHO, Rome, pp. 49–66.

Rao, B.R.S., Rao, D.V.B., Rao, V.B., 2004. Decreasing trend in the strength of Tropical Easterly Jet during the Asian summer monsoon and the number of tropical cyclonic system over Bay of Bengal. Geophysics Research Letter 31. doi:10.1029/2004GL019817.

Rodrigo, S., Esteban-Parra, M.J., Pozo-Vázquez, D., Castro-Díez, Y., 2000. Rainfall variability in southern Spain on decadal to centennial time scales. International Journal of Climatology 20 (7), 721–732.

Rotstayn, Leon D., Lohmann, Ulrike, 2002. Tropical rainfall trends and the indirect aerosol effect. Journal of Climate 15, 2103–2116.

Rupa Kumar, K., Pant, G.B., Parthasarathy, B., Sontakke, N.A., 1992. Spatial and subseasonal patterns of the long term trends of Indian summer monsoon rainfall. International Journal of Climatology 12, 257–268.

Sathiyamoorthy, V., 2005. Large scale reduction in the size of the TROPICAL Easterly Jet. Geophysics Research Letter 32. doi:10.1029/2005GL02956.

Singh, Nithyand, Sontakke, N.A., 1999. On the variability and prediction of rainfall in the post-monsoon season over India. International Journal of Climatology 19, 309–339.

Singh, O.P., Ali Khan, Tariq masood, Rehaman, Sazedur, 2001. Has the frequency of intense tropical cyclones increased in the north Indian ocean? Current Science 80 (475), 575–580.

Soman, M.R., Krishnakumar, K., Singh, N., 1988. Decreasing trend in the rainfall of Kerala. Current Science 57, 7–12.

Srivatsava, H.N., Dewan, B.N., Dikshit, S.K., Prakasa Rao, G.S., Singh, S.S., Rao, K.R., 1992. Decadal trends in climate over India. Mausam 43, 7–20.

Thapliyal, V., Kulshrestha, S.M., 1991. Climate changes and trends over India. Mausam 42, 333–338.

Appendix II

List of research articles published

Rao, G. S. L. H. V. P. and Krishnakumar, K. N 2005. Monsoon onset over Kerala (India): 1870-2004. *J. of Agrometeorology*. 7(2):161-167.

Rao, G.S.L.H.V.P, Gopakumar, C.S., and Krishnakumar K. N. 2006. UV-B radiation in the tropical monsoon climates. Journal of Agrometeorlogy. 10(2):141-145.

Krishnakumar, K. N and Rao, G. S. L. H. V.P. 2006. Selection of PET formulae for estimation over the Palghat Gap of Kerala. *J. of Agrometeorology*. 8(2):269-273.

Krishnakumar, K. N and Rao, G. S. L. H. V. P. 2006. Climatological droughts in the tropical monsoon climate of Kerala, India. *J. of Agrometeorology*. 8(2):248-253.

Krishnakumar, K. N and Rao, G.S.L.H.V.P, Gopakumar, C.S and Mohan, H. S. R, 2007. Rainfall variability during southwest monsoon over Kerala (India: 1871-2005). Indian Journal of Polar Sciences, Vol 1(1) .pp 81-87.

Krishnakumar, K. N and Rao, G. S. L. H. V. P. 2008. Trends and variability in northeast monsoon rainfall over Kerala (India):1871-2005. *J. of Agrometeorlogy* 10(2):123-126.

Krishnakumar, K. N., Rao, G .S. L .H .V. P. and C. S. Gopakumar C. S 2008. Climate change at selected locations in the humid tropics. *J. of Agrometeorlog*, 10(1):59-64.

Rao, G. S. L. H. V. P., Mohan, H. S. R., Gopakumar, C. S and Krishnakumar, K. N. 2008. Climate change and cropping systems over Kerala in the humid tropics. *J. of Agrometeorology* (Special issue-Part 2): 286-291. pp. 286-291.

Krishnakumar, K. N, Rao, G. S. L. H.V. P. and Gopakumar C. S 2009. Rainfall trends in twentieth century over Kerala, India. *Atmospheric environment* 43: 1940-1944.