Agrometeorology of coconut in Kerala

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PREFACE

The coconut production is vulnerable to weather vagaries such as floods and droughts. The effect of summer drought is much more pronounced in coconut production, when it is grown under rainfed conditions. Low productivity in Kerala is attributed to several factors *viz.*, high rainfall during monsoon, erratic summer showers, lack of sufficient irrigation during summer, poor nutrient management of soils, prevalence of root (wilt) disease, bud rot, incidence of stem bleeding and attack of mite and the reluctance to adopt efficient management practices such as application of fertilizers due to the unprofitable price.

Global warming is real in Kerala. According to IMD the maximum temperature has risen by 0.8°C and the minimum by 0.2°C. The trend in monsoon and annual rainfall of Kerala was declining since last 60 years. The frequency of occurrence of floods and droughts is likely to be more under the projected climate change scenario. As a result, the coconut productivity is likely to be adversely affected. Hence, there is a need to understand the impact of abiotic stresses such as temperature, rainfall *etc.* and its effects *ie.* on different phenophases of coconut which will help in ensuring mitigation strategies for sustenance of coconut productivity.

Thus, this technical bulletin "Agrometeorology of coconut in Kerala" which is focused on production of coconut in relation to climate is serialized in to seven chapters. The first chapter deals with the origin and distribution of coconut and importance while the second chapter is on Agroclimatic Characterization. The information on crop weather relations is well explained in the third chapter. The fourth chapter deals with the drought and coconut production. The study on climate change and its real effect on coconut productivity are explained in the chapter five. Chapter six deals with forecasting models of production in coconut and the final chapter seven is on Agrometeorological techniques for production enhancement in coconut.

I hope that this publication will serve as a valid reference material to all stake holders involved in coconut production, processing industry, trade besides scientists, extension workers and students.

22nd April, 2016

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B. Ajithkumar

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1. INTRODUCTION

1.1 Origin and distribution

The home of coconut might have been somewhere in south East Asia, most probably in Malaysia or Indonesia. It moved eastwards to the Pacific region and further to America. Towards the west, it moved to India and Madagascar over the calm tropical waters. The crop is grown on an area of about 9 million ha with the production of 33,700 million nuts in the world. In India, the area under coconut is 1513 thousand ha and production is 9700 million nuts.

1.2 Importance of coconut

The coconut palm is one of the most beautiful and useful trees in the world, grown in more than 80 countries of the tropical region. It supplies food, water and shelter and also supplies raw material to number of industries intimately connected with domestic as well as economic life. All the parts-of the wonder palm are useful in one way or other. On account of this, the palm has been regarded as *Kalpavriksh* (Tree of heaven).

The following products of coconut are useful to human beings.

1.2.1 Coconut Water:

It is liquid endosperm of tender coconut and is used as refreshing and pleasant drink and as a useful substitute for saline glucose in intravenous infusion. It increases blood circulation in the kidneys.

1.2.2 The Wet Meat or Kernel:

The kernel or endosperm is an important article of food being used in culinary purpose. The milk or cream obtained by squeezing the grated kernel diluted in water is used in the preparation of foods and also used in cosmetic industry. The fresh kernel includes moisture 45%, protein 4%, fat 37%, minerals 4% and carbohydrates 10%.

1.2.3 Desiccated Coconut:

It is dried out disintegrated coconut meat. It has great demand in confectionary and other food industries.

1.2.4 Coconut Flour:

Partially defatted edible coconut grating is an excellent product and used in bakery and confectionary.

1.2.5 Toddy and Toddy Products:

A sugar containing juice which is obtained by tapping unopened spadix is known as toddy. From this vinegar, jaggery and sugar is prepared. From fermented toddy alcohol is prepared.

1.2.6 Coconut Oil and Oil Cake:

Dried copra gives 60 to 67% oil and 33-40% oil cake. The coconut oil is in great demand for edible purposes, for soap making etc. The oil cake is used to feed cattle and poultry.

1.2.7 Coir and Coconut Fiber:

It is an important commercial product obtained from the husk of coconut. India contributes about 50% coir production. The world coir production is 0.282 million tones.

1.2.8 Miscellaneous Uses:

The endocarp or shell is used for fuel, making shell charcoal, activated carbon etc. Fancy utensils can be prepared from shell of coconut. The stem is used for construction of houses and leaves are used for thatching, fencing and making baskets and broomsticks.

1.3 Adaptation and Geographical distribution

India is one of the largest coconut producing countries in the world with an area of about 1.89 million hectares and annual production of 12812.7 million nuts (CDB, 2003). The Country ranks third on the world map of coconut after Philippines and Indonesia. It provides livelihood to small and marginal farmers, scattered in 18 states and three Union Territories in the country. The State of Kerala ranks first in coconut area (49.6%) and production (44.7%) within this country. The very name 'Kerala' is derived from its association with the coconut palm. called *kera vriksha* in Sanskrit.

1.4 Soil and Climate

Coconut palm thrives in almost all types of well drained soils such as coastal sand. red loam, laterite, alluvial and reclaimed soils of marshy low lands. Coconut is a crop suited for humid tropics. Though it is mainly grown in the coastal plains it is possible to grow even at elevation of 600 to 900 m above mean sea level in areas near the equator where the temperature remains favourable. Among the climatic factors affecting the palm, rainfall is the most important. A rainfall of 1000 to 2250 mm per annum evenly distributed throughout the year appears to be most congenial. Regions with long and pronounced dry spells are not suited to its growth.

Coconut palm requires climate which may be neither very hot nor very cold. The maximum mean annual temperature for good growth is about 27°C with a diurnal variation of about 6° to 7°. Persistent high humidity is harmful and incidence of bud rot is more under such conditions. The palm requires bright sunshine of about 2000 hours a year.

2. AGROCLIMATIC CHARACTERIZATION

2.1 Spatio-temporal changes in area, production and productivity of coconut

Coconut is generally grown all over the state. The productivity of coconut in Kerala is lesser than other major producing states, may be due to several factors such as

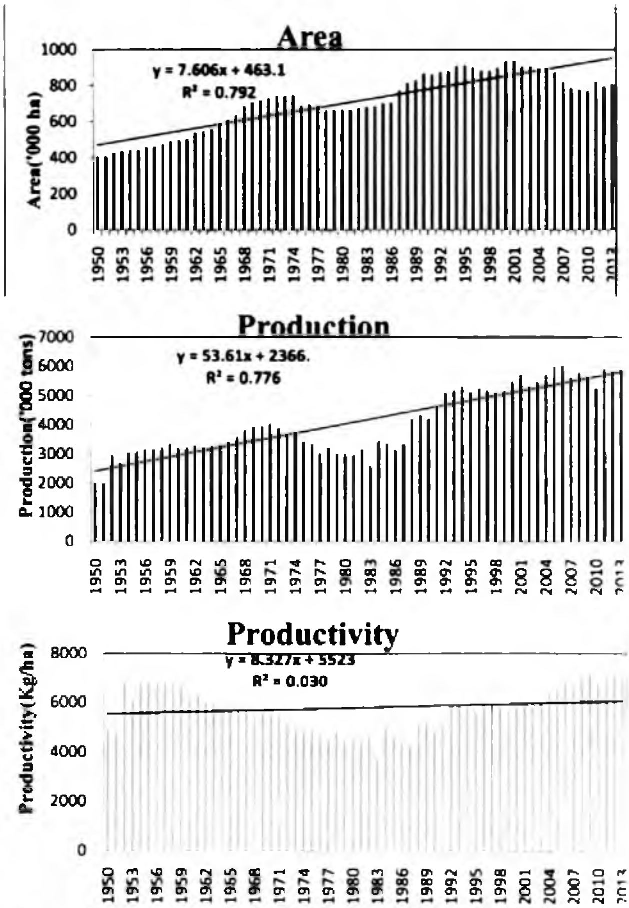

Fig. 2.1: Trends in area, production and productivity of coconut in Kerala (1950-2013)

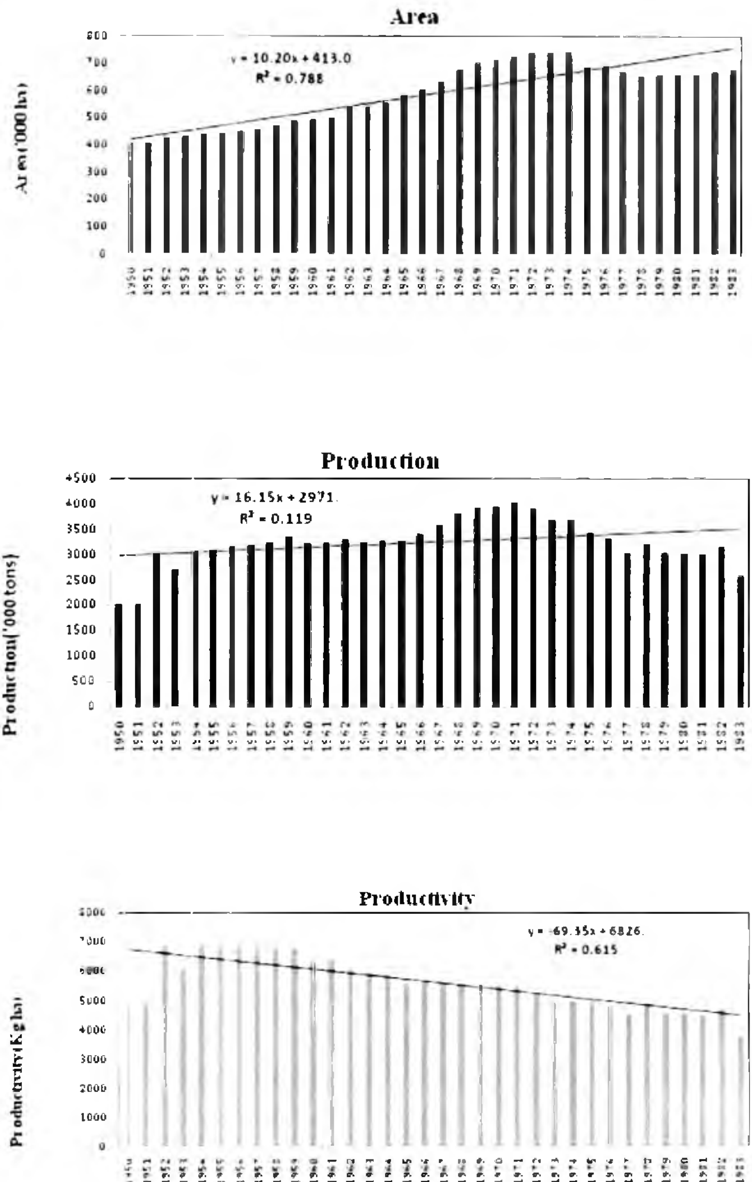

Fig. 2.2: Decade-wise trends in area, production and productivity of coconut in Kerala (1950-1983)

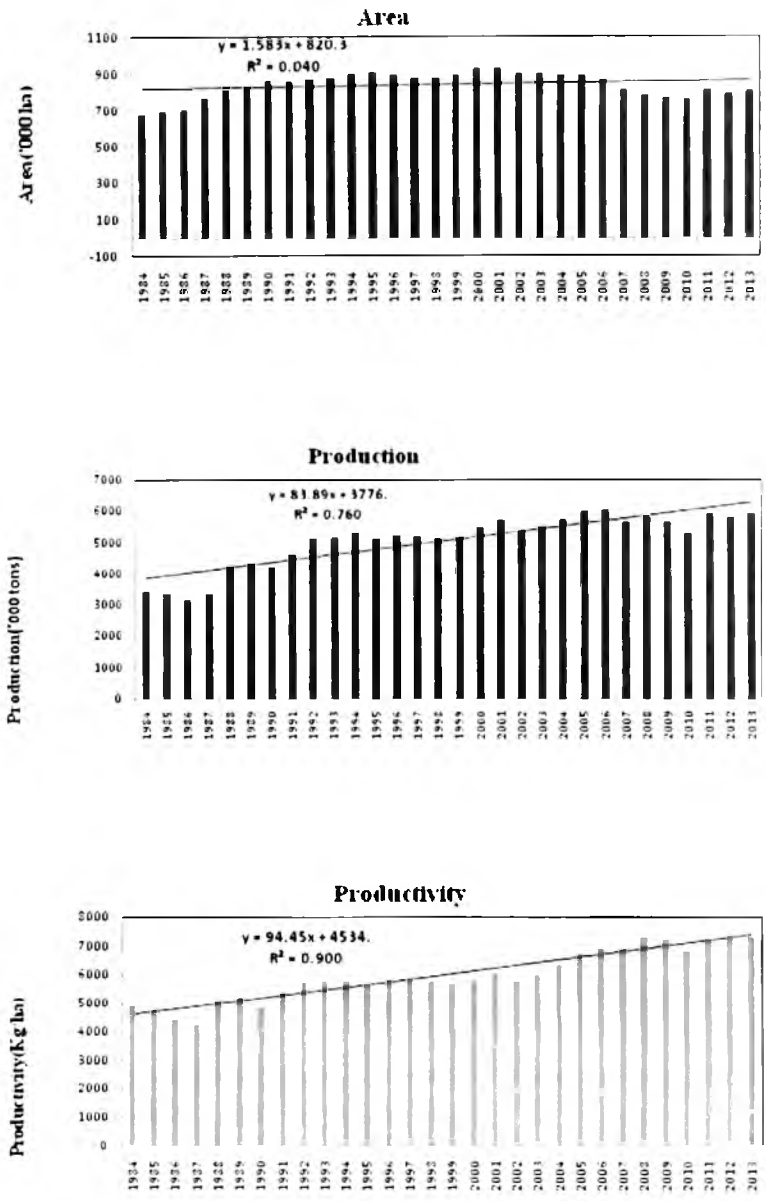

Fig. 2.3: Decade-wise trends in area, production and productivity of coconut in Kerala (1984-2013)

high rainfall during monsoon, insignificant rainfall in several parts of Kerala during summer months *etc.* Production of coconut is concentrated specifically in Kozhikode district followed by Malappuram. The lowest production is in Wayanad district. Area, production and productivity of coconut from 1950 to 2013 are given in Fig.2.1. Decade - vise trends in area, production and productivity during 1950-1983 and 1984-2013 also given separately (Fig. 2.2 and 2.3). The area under coconut during the early tri-decade (1950-1983) was showing an increasing trend while no trend was followed in the last tri-decade (1984-2013). The production of coconut was increased more during the latest tri-decade (1984-2013) compared to early tri-decade (1950-1983). The productivity of coconut was decreased during the early tri-decade (1950-1983) while, it was increased in the latest tri-decade (1984-2013). Even though the area was not increased in the latest tri-decade (1984-2013), the productivity was increased and this may be due to the introduction of high yielding varieties of coconut.

2.2 Delineation of production zones

The net sown area in the state has been classified / demarcated into different categories of production zones. The criteria adapted for the categorization is the area under the crop and those districts contributing above 15% of the area in the state are termed as primary zone and districts contributing in between 5-15% of the net area sown under the crop are classified as secondary and the rest of the districts (below 5%) as tertiary zone (Table 2.1 and Fig. 2.4). This type of categorization helps in planning and implementing projects to expand areas under the crops currently grown or to introduce new crops or their cultivars into the new area.

Table 2.1 Production zones of coconut in Kerala

Zone	Area (ha)	Name of districts
Primary zone	123967.0	Kozhikkode
Secondary zone	571974.0	Thiruvananthapuram, Kollam, Ernakulam, Thrissur, Palakkad, Malappuram, Kannur, Kasargod
Tertiary zone	110122.6	Alapuzha, Kottayam, Pathanamthitta, Idukki, Wayanad
Total	**806063.6**	

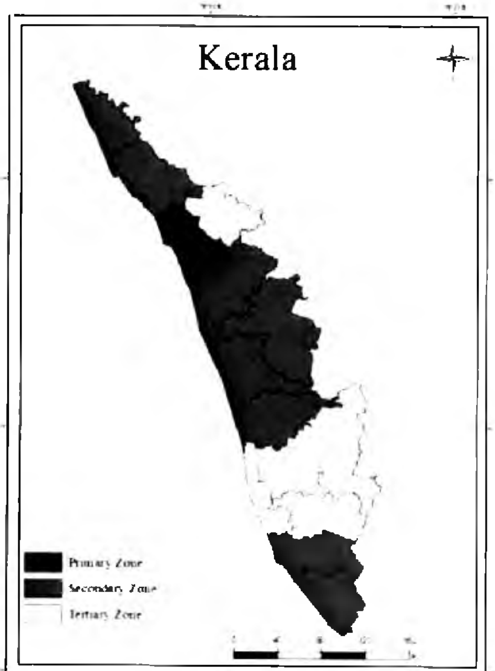

Fig. 2.4 Production zones of coconut in Kerala

3. CROP WEATHER RELATIONSHIP

The study was undertaken at the Department of Agricultural Meteorology, College of Horticulture, Vellanikkara from February 2002 to June 2007. Ten (eight year old coconut palms) palms each of the four cultivars were randomly selected for the study. The four test cultivars *viz.*, Tiptur Tall, Kuttiadi (WCT), Kasargod (WCT) and Komadan (WCT) were selected for taking up the field experiment.

3.1 Phenology of coconut

Phenology is the study of the response of living organisms to seasonal and climatic changes in which they live. Phenology is the study of the timing of recurring biological 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 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 (3½) years from primordium initiation to harvest of coconut unlike seasonal fruit crops or annual crops. Patel (1938) has been traced the evolution and development of inflorescence of the coconut palm. 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. 3.1.

The primordia of the branches of inflorescence 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 and through active and ripening phases. 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.

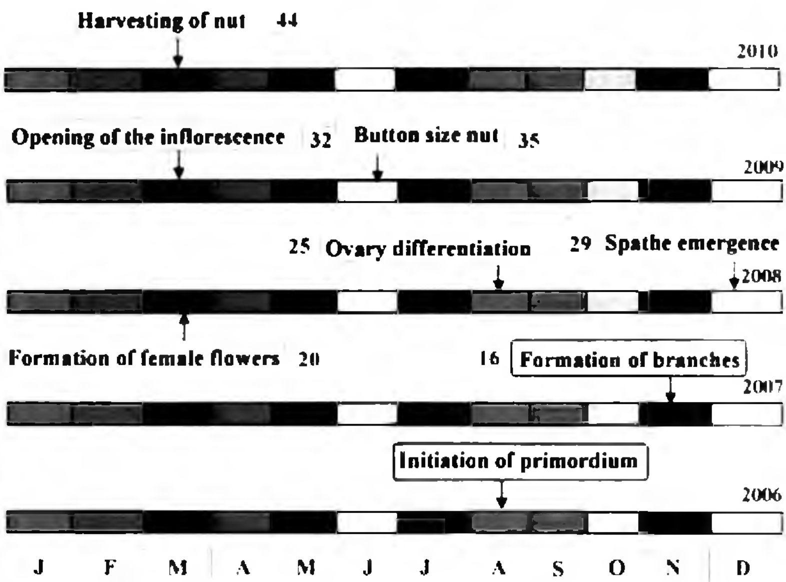

Fig. 3.1: Evolution and development of inflorescence in coconut

3.2 Functional leaves

The coconut leaf known as frond 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 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.

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

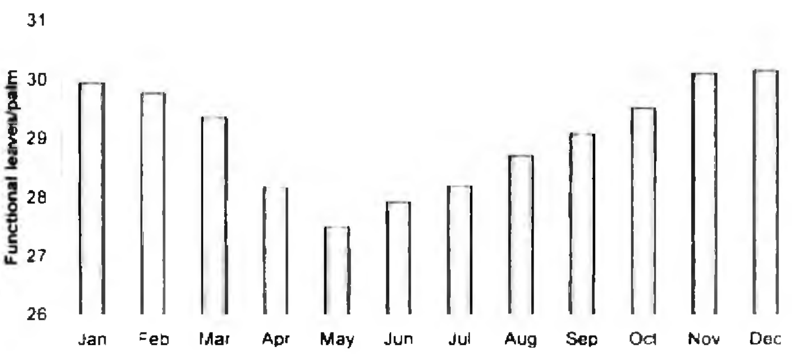

Fig. 3.2: Mean monthly functional leaves

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. 3.2). The functional leaves present on the crown was maximum (30.2/palm/month) during December while minimum (27.5/palm/month) was observed during 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 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.

3.2.1 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 shedding of leaves varies from season to season depending upon weather conditions.

The monthly average 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/palm/month each) in September and October, thereafter it gradually increases from December onwards, reaching to its maximum (1.9/palm/month) in May (Table 3.1). 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.

Table 3.1 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**

As a whole, the seasonal leaf shedding was maximum (41.2%) during summer (Fig.3.3) and winter (31%) while minimum (12.4%) during post monsoon and rainy seasons (15.3%). The results obtained were in accordance with Patel (1938).

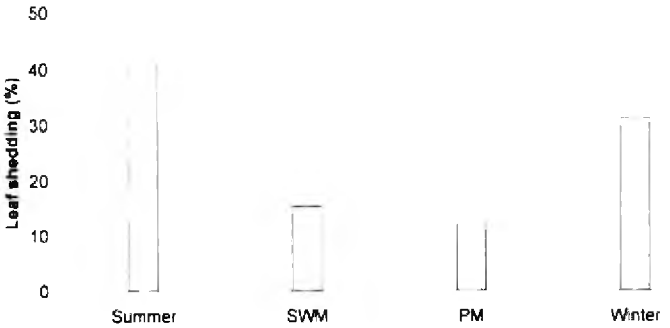

Fig. 3.3: Mean seasonal leaf shedding (%) in coconut from 2002 to 2007

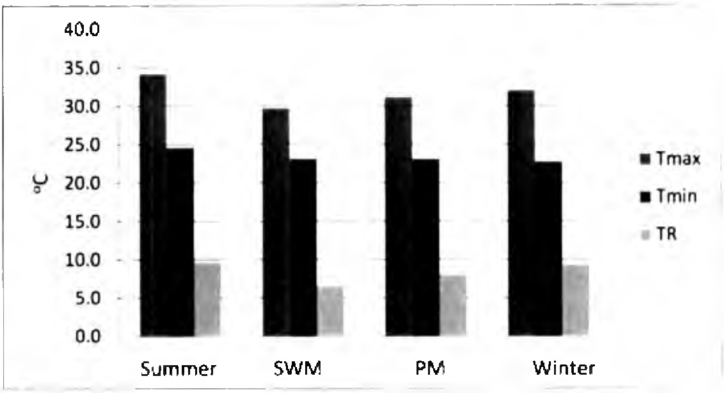

Fig. 3.4: Mean seasonal maximum temperature (Tmax), minimum temperature (Tmin) and temperature range (TR) in °C from 2002 to 2007

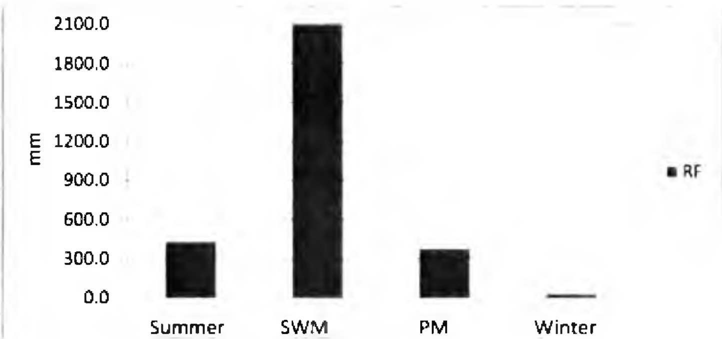

Fig. 3.5: Seasonal rainfall (mm) from 2002 to 2007

Rise in ambient air temperature, temperature range, vapour pressure deficit, low rainfall coupled with high eva potranspiration 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 (Fig. 3.4 and 3.5). 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 Palakkad gap from November/December to January/February. All the cultivars recorded maximum leaf shedding during summer 2004 due to prolonged dry spell from 1st November to 28th March 2004 coupled with high air temperature (1-3°C rise against normal). It led to drying of older leaves, resulting in leaf shedding.

3.3 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.

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 and 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 3.2). 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 3.2. Mean monthly spathe emergence (palm/month) in coconut

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 rainfall (Appendix 1-IV), which results in better availability of soil moisture. 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. 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 water logging and lack of aeration in coconut root zone.

3.4 Number of Spathes present in coconut

The number of spathes on the crown significantly varied from year to year, having maximum (3.4/palm) during winter 2004-05 and minimum (1.4/palm) during southwest monsoon 2002 (Table 3.3). 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 3.3 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 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. 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 (Appendix I-IV).

3.5 Spathe duration in coconut

The number of weeks taken from initiation of spathe to spathe opening (spadix emergence) during the study period varied from year to year 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. 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 period in respective seasons (Table 3.4).

Table 3.4 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 (Appendix I,II and IV). 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 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 along with optimum maximum and minimum temperatures and low vapour pressure deficit.

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).

Spadix emergence varied significantly from year to year, 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 3.5).

Table 3.5 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 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 (Appendix IV) 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 95.2 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 (Appendix I-IV).

3.7 Female flower production

The inflorescences of the coconut are formed in the axils of every leaf of bearing tree. The coconut is a monoecious plant producing male and female flowers separately in the same tree.

The flowers are light yellow in colour. 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 production of female flowers is an important character as it influences to greater extent the final yield of ripe nuts.

Female flower production varied significantly from year to year, 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 3.6).

Table 3.6 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

3.7.1. 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.

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 3.7). 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 intermediate (61.5%) during southwest monsoon and post monsoon (61.1%).

Table 3.7 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

3.8 Coconut production

The female flowers that are not shed develop and become fully mature in the course of about 12 months. Critical stages of the development of the spadix have great influence on yield of nuts.

Coconut production varied significantly from year to year, 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 and 2003 (54.3 nuts/year).

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 3.8).

Table 3.8 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 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. The linear regression equation developed based on these monthly weather variables at various critical stages and monthly nut yield is as follows.

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

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 ($F (7, 64) = 29.574$, $P < 0.001$).

4. SUMMER DROUGHTS AND COCONUT PRODUCTION OVER KERALA

Drought is a relative term used universally with reference to deficiency of rainfall when compared to normal rainfall of a given location and is a natural hazard that has significant impact on economic, agricultural, environmental and social aspects.

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 (Table 4.1).

Table 4.1 Drought classification based on the departure of aridity index (Ia) from the median

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

ó – standard deviation of aridity index

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 4.2), 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.

Fig. 4.1 Effect of droughts on coconut production

4.3 Impact of droughts on coconut productivity

The decline in coconut productivity of Kerala was maximum during 1983-84 (19.2%) when compared to previous years. 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.4.2).

Fig. 4.2 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 drought years 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. 4.3). The low decadal production during 1981-90 is mainly attributed to more number of droughts experienced during that period.

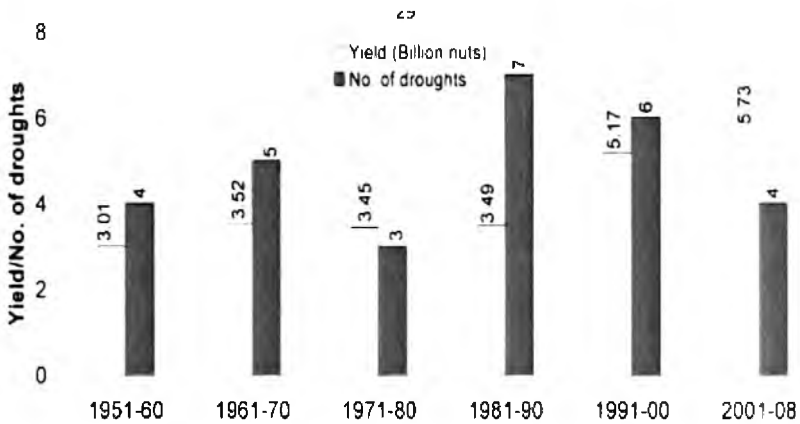

Fig. 4.3 Decade-wise number of droughts versus coconut production

The three decadal average numbers of droughts were more in 1981-08 and the coconut production was 4.8 billion nuts (Fig. 4.4). The number of droughts have increased to 50% in 1981-2008 when compared to 1951-80 and the yield was increased only 45%.

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

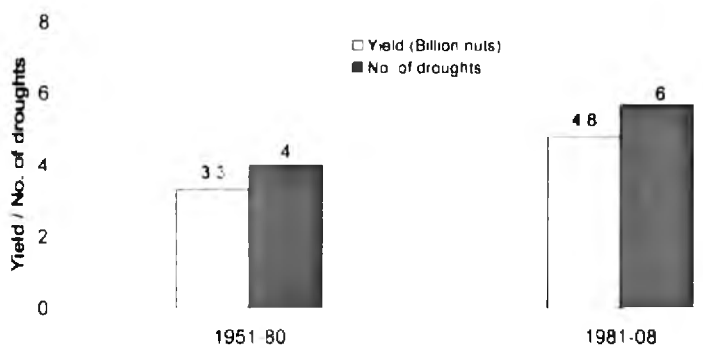

Fig. 4.4 Tri decade-wise number of droughts versus coconut production

situation. Therefore, summer droughts were worked out considering rainfall from December to May at RARS, Pilicode, Kasaragod district. 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 4.3).

Table 4.3 Occurrence and intensity of summer droughts at RARS, Pilicode from 1983 to 2008

Decade	Intensity and occurrence of droughts					
	Moder	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.*, 1993). 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.

4.4 The effect of droughts on monthly nut yield

4.4.1 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. 4.5).

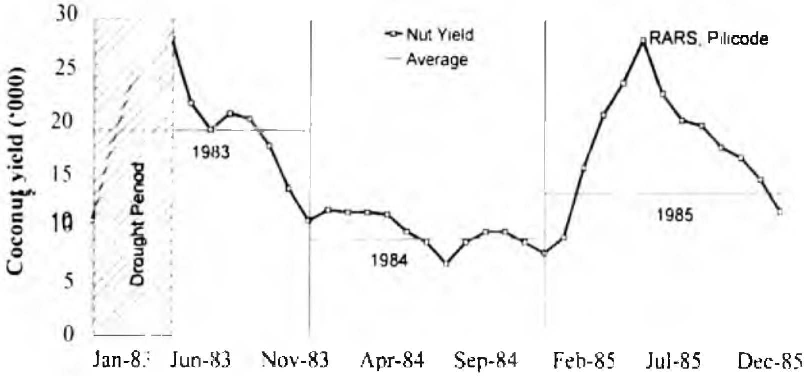

Fig. 4.5 Effect of drought during summer 1983 on coconut yield at RARS, Pilicode

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 8^{th} month after the drought period was over and maximum decline in the yield was noticed in 13^{th} month after the drought period was over and it was continued up to 19^{th} month.

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

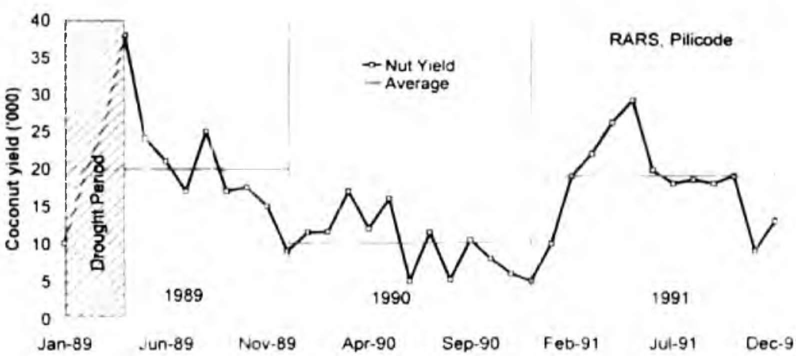

Fig. 4.6 Effect of drought during summer 1989 on coconut yield at RARS, Pilicode

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. 4.6). 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.

4.4.2 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. 4.7). It revealed

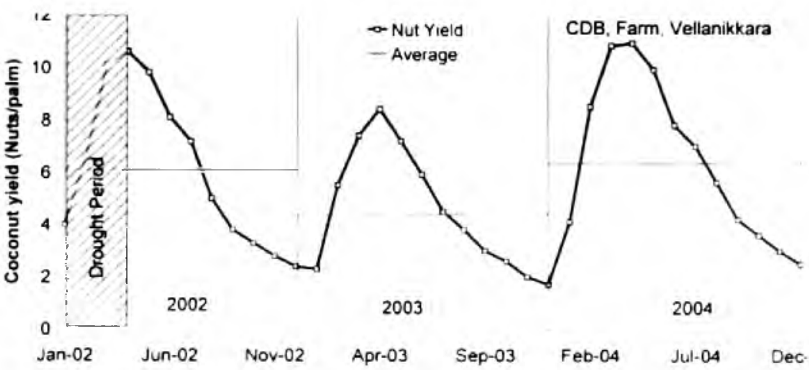

Fig.4.7 Effect of drought during summer 2002 on coconut yield at CDB Farm, Vellanikkara

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.

Similar was the case in summer drought during 2004 with the dry spell, begining from 2nd November, 2003 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 (578.3 mm). 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.4.8).

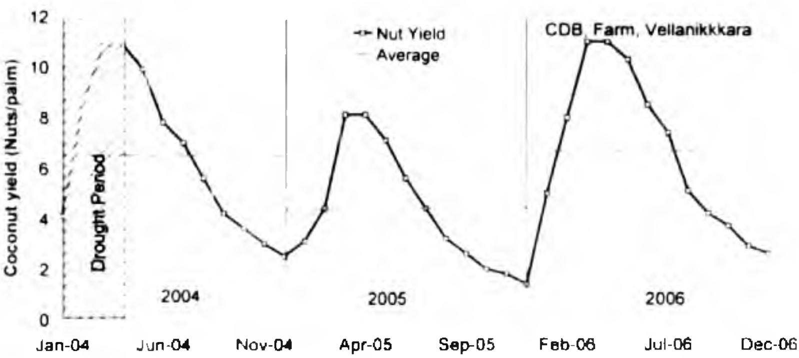

Fig. 4.8 Effect of drought during summer 2004 on coconut yield at CDB, Farm, Vellanikkara

4.4.3 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 (7th month) 1984 onwards and it continued up to November 1984 (Fig 4.9).

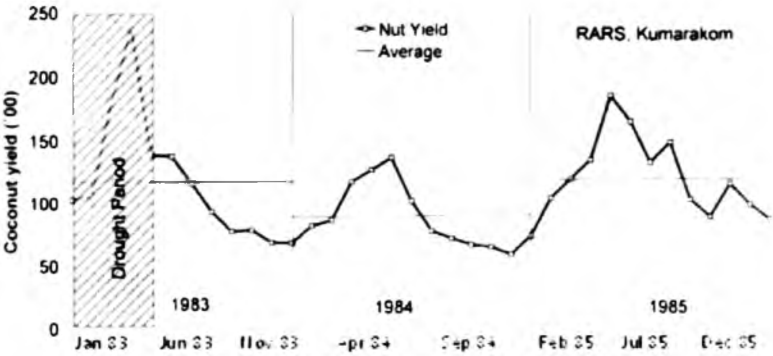

Fig. 4.9 Effect of drought during summer 1983 on coconut yield at RARS, Kumarakom

Maximum decline in the monthly nut yield was noticed in the month of July, 1984 (13^{th} month after the dry period was over).

4.4.4. 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.4.10).

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.4.11).

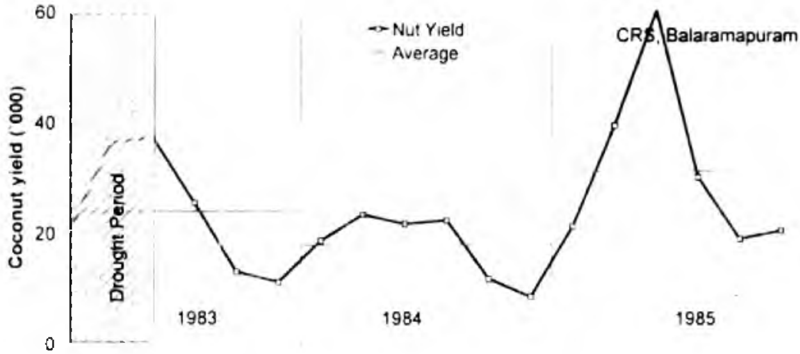

Fig. 4.10 Effect of drought during summer 1983 on coconut yield at CRS, Balaramapuram

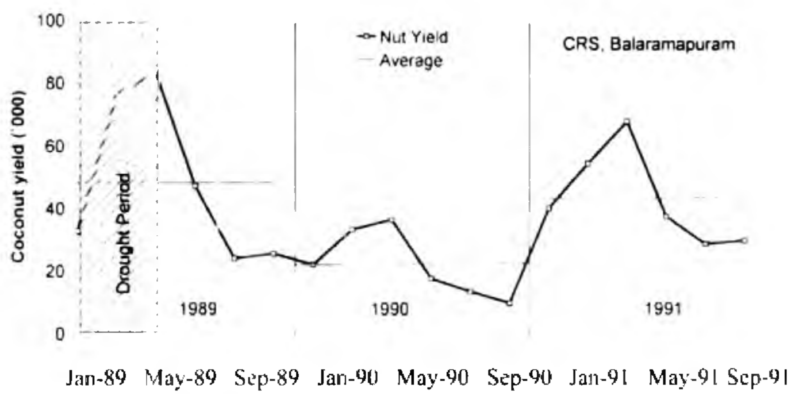

Fig. 4.11 Effect of drought during summer 1989 on coconut yield at CRS, Balaramapuram

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. 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.

5. CLIMATE CHANGE AND COCONUT PRODUCTION IN KERALA

Climate and Climatic change in recent decades has become the subject of world-wide discussion. The recent drought in kharif 1987, 2002 and 2009 due to deficient monsoon rainfall resulted in low *kharif* foodgrains production in India despite different crop strategies coupled with agrotechniques 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 4th November 1982 to 13th 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.

5.1 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 years. All the above three low coconut productivity years fell in the decade 1981-90 (Fig 5.2). 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 in 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.

5.2 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 (5670 nuts/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 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. 5.1 and Fig.5.2). Therefore, there is a threat to coconut productivity in the ensuing decades due to climate variability and climate change (Fig.5.3). 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 lions share in coconut productivity of the country.

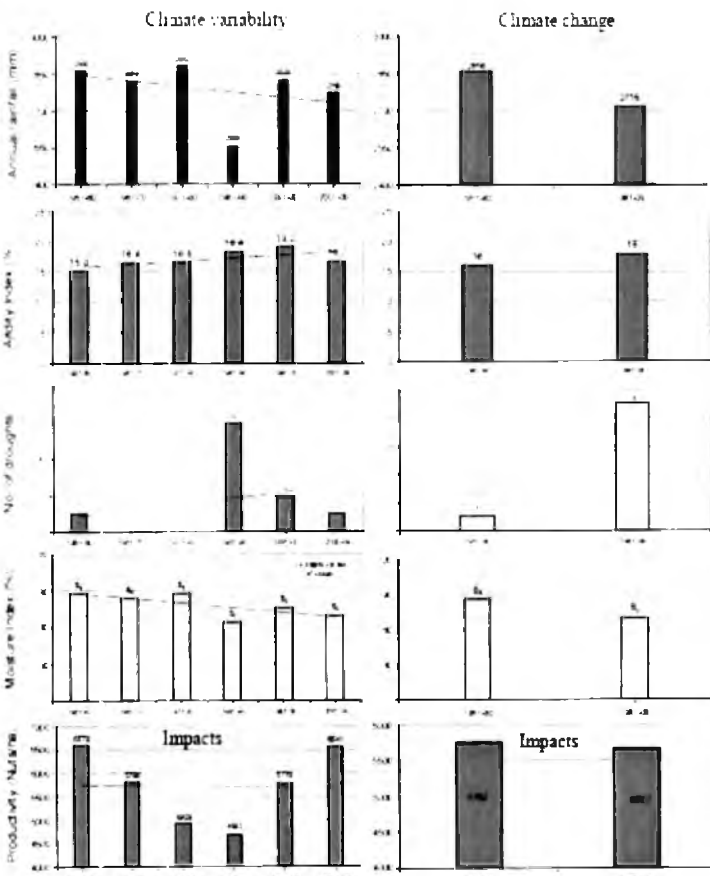

Fig. 5.1 Decadal and tri-decadal annual rainfall, aridity index, number of summer droughts, moisture index and productivity of coconut

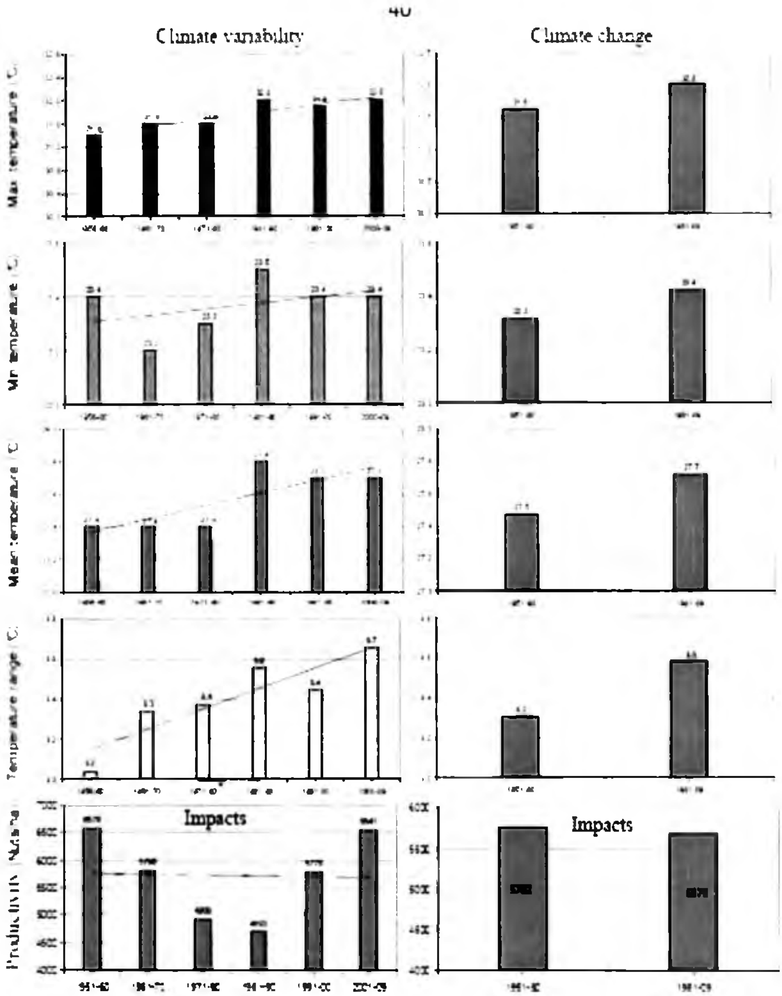

Fig. 5.2 Decadal and tri-decadal maximum temperature, minimum temperature, mean temperature, temperature range and productivity of coconut

6. CROP YIELD FORECASTING AND MODELLING OF COCONUT

6.1 Effect of weather variables on coconut yield

6.1.1 Temperature

The maximum temperature during May showed significant negative influence on coconut productivity during the current year as well as one, two and three year lag periods. 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 periods (Table 6.1). Rest of the months had no significant influence on coconut productivity.

Table 6.1: 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.

The minimum temperature during May had significant negative influence on coconut productivity during current, one year and two year lag periods (Table 6.2).

Table 6.2 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 6.3). 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.

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 to harvest had negative effect on productivity.

Table 6.3 Correlation between mean temperature and coconut productivity

Month/season	Current year	Lag period		
		One year	Two year	Three
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 temperature range (difference of between maximum and minimum) during May showed significant negative influence on coconut productivity during the current year as well as one, two and three year lag periods (Table 6.4).

Table 6.4 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.

6.1.2 Rainfall

The May rainfall had significant positive influence on coconut productivity during the current year as well as one, two and three year lag periods. Rainfall during October had significant positive influence on productivity during one year and three year lag period (Table 6.5). Rest of the months had no significant influence on coconut productivity.

Table 6.5 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 and also during one year, two year and three years lag period.

6.1.3 Index of moisture adequacy

Correlations between the index of moisture adequacy during the current year as well as one, two and 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 6.6). Average index of moisture adequacy from December to May during one year lag period had significant positive correlation with coconut productivity.

Table 6.6: 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

6.1.4 Humidity Index

The correlation between humidity index during current year as well as one, two and three years lag period and coconut productivity indicated that humidity index of August had significant negative influence on productivity of two and three year lag period (Table 6.7). Rest of the months had no significant influence on coconut productivity.

Table 6.7: 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

6.2 Yield forecasting models in coconut

6.2.1 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 are involved in 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 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.

$$Y = -34.743*X_1 + 102.872*X_2 + 2.38*X_3 - 0.899*X_4 + 2.54*X_5 - 1.476*X_6 + 7.899*X_7 -5.371*X_8 + 0.59*X_9 + 3.005*X_{10} -17.129*X_{11} + 8.376*X_{12} - 13.988*X_{13} + 46.678*X_{14} + 5.312*X15 - 4.488*X16 - 0.549*X_{17} - 1.071*X18 + 7.835*X19 + 9.975*X20 + 1.426*X21 + 11.698*X_{22} - 22.258*X_{23} - 32.157*X_{24} + 21.789 X_{25} + 160.818*X_{26} + 2.947*X_{27} - 5.436*X28 + 0.284*X29 - 0.739*X30 - 8.88*X31 - 15.183*X32 -16.953*X33 + 16.307*X34 + 9.02*X_{35} - 11.329*X_{36} + 21.757*X_{37} + 22.987*X_{38} + 2.444*X_{39} - 0.75*X_{40} + 1.17*X_{41} - 0.698*X42 + 2.265*X43 - 24942.3$$

$(R^2 = 0.969)$

Where Y= Annual productivity (nuts/ha)

$$Y = -39.152*X_1 + 160.788*X_2 + 2.362*X_3 - 0.054*X_4 + 1.939*X_5 -1.582*X_6 + 11.229*X_7 + 1.197*X_8 + 0.613*X_9 -5.715*X_{10} -23.428*X_{11} + 15.58*X_{12} + 0.173*X_{13} +$$

$42.854*X_{14} + 3.713*Xi5 - 3.487*X_{16} - 0.668*X_{17} - 1.301*XI_{8} + 14.728*X_{19} + 4.95*X_{20} + 9.612*X_{21} + 7.606*X_{22} - 11.084*X_{23} - 39.3 04*X_{24} + 33.024*X_{25} + 36.683*X_{26} + 1.971*X_{27} - 4.754*X_{28} - 0.733*X_{29} - 0.573*X30 - 4.545*X_{31} - 17.718*X_{32} - 12.114*X_{33} + 11.443*X_{34} + 2.929*X_{35} - 10.818*X_{36} + 35.854*X_{37} + 39.521*X_{38} + 2.137*X_{39} - 0.247*X_{40} + 1.451*X_{41} - 0.601*X_{42} + 7.057*X_{43} - 28700$ ($R^2 = 0.993$)

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 6.8).

Table 6.8 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 6.9). 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 6.9 Actual and estimated coconut production of Kerala from 1994-95 to 2009-10

Year	Coconut production of Kerala (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	-

7 AGROMETEOROLOGICAL TECHNIQUES FOR PRODUCTION ENHANCEMENT IN COCONUT

Among various crops, plantation crops form the backbone of the agriculture sector in Kerala, since they hold a major share of agricultural economy. But the production of these plantation crops is affected by various weather aberrations, leading to decline in yield and reflecting in the overall economy of Kerala. Various plantation crops require different weather conditions for their optimum growth. If the required weather parameters are not available to the crops, growth may be severely affected. So, certain agrometeorological techniques need to be taken to overcome the ill effects of weather and also to enhance the yield of crops. Some of the important agrometeorological techniques to enhance yield in plantation crops are discussed below.

Among the meteorological variables, rainfall is one of the important parameters that affect production of most of the plantation crops. Hence conservation of available soil moisture is important for mitigating water deficit during prolonged drought periods, at least to a certain extent. Various methods like contour bunding, trenching, pitting and construction of check-dams are used for conservation of soil moisture. However for managing atmospheric drought, crop plants which can adapt to changing soil and atmospheric conditions and yield satisfactorily have to be recommended. As the plantation crops are grown under different soil types having variation in hydrophysical characteristics, different methods have to be adopted to conserve soil moisture such as soil mulching (Rajagopal *et al.*, 2002).

Coconut is a crop which produces nuts round the year, require adequate supply of water for its unhindered growth. As fertilizer application is done after monsoon and a dry period follows thereafter, supplemental irrigation can improve coconut productivity to a large extent. Moisture stress leads to decreased yield, so economic utilization of available irrigation water and adoption of the soil moisture conservation practices can be done to control drought. Drip irrigation can be followed (Fig.7.1), since it can save up to 40% of water compared to basin and flood irrigation. Irrigation is necessary to avoid nut dropping, which leads to reduction in yield if the delay of the monsoon is up to 30 days and irrigation during summer months helps to sustain the yield of root wilt affected palms. In order to conserve moisture and thereby avoid stresses to the palms during dry periods, coconut husk with concave side up can be buried (Fig.7.2) in linear or circular trenches between rows of palms or around the palm. Instead of husk, coconut pith can also be buried (Alice and Peter, 2007). Mulching of coconut basin (Fig.7.3) can be done with green/dry leaves, coir pith or coconut husk. Mulches reduce loss of soil moisture and create good microclimate in soil for proper growth of plant roots and soil flora and fauna. During rainy season, excess water may be conserved in small trenches dug out in levelled lands.

In sloppy areas, land may be terraced and trenches dug across. This will facilitate maximum percolation of rainwater and water storage. For moisture conservation, lower most 3-5 leaves may be cut and removed. To minimise heat load on stem, apply lime solution (Fig.7.4) up to a height of 2-3 m at start of summer season.

Fig.7.1 Drip irrigation in coconut

Fig.7.2 Husk burial in coconut

Fig.7.3 Mulching in coconut

Fig.7.4 White washing in coconut

Regulation of soil temperature and control of soil erosion can be done by growing cover crops and green manure crops. All these field problems can be addressed by proper and timely agromet advisories.

8. SUMMARY

The present investigation on "Agrometeorology of coconut in Kerala" was made based on the experiment 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 number of functional coconut leaves present on the crown was low during summer due to higher leaf shedding in this season. The leaf shedding in coconut was less during post monsoon and high during summer while intermediate in southwest monsoon and winter seasons. The summer drought during 2002 and 2004 reduced the number of spathes during 2002-03 and 2004-05. 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 during winter compared to other seasons.

The cumulative effect of more spathe emergence and its duration during post monsoon, followed by winter led to more spadix production in summer. High spadix production can be attributed to high rainfall during 32 months before (July-September) the spadix production, resulted in better availability of soil moisture and this may favour congenial environment for the primordium initiation and thus maximum spadix production during summer season.

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.

The effect of weather variables during the two critical stages *viz.*, primordia initiation and ovary development is vital for final female flower production. When all the biotic and abiotic factors are considered, the seasonal variation in button shedding is predominantly influenced by soil moisture and vapour pressure deficit along with the number of female flowers. The primordium stage was most sensitive to moisture stress, followed by ovary development stage and the stage of button in coconut.

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.

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. 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 taking pro-active measures as a part of climate change adaptation strategy to sustain coconut productivity in the State of Kerala.

Some agrometeorological practices like burial of coconut husk, coconut pith and mulching of coconut basin with green/ dry leaves, coir pith or coconut husk creates good microclimate in soil for proper growth of plant roots and soil flora and fauna. During rainy season, excess water may be conserved in small trenches dug out in levelled lands. In sloppy areas, land may be terraced and trenches dug across. This will facilitate maximum percolation of rainwater and water storage. For moisture conservation, lower most 3-5 leaves may be cut and removed. To minimise heat load on stem, apply lime solution up to a height of 2-3 m at start of summer season. Soil temperature regulation and control of soil erosion can be done by growing cover crops and green manure crops.

References

Alice, K. and Peter, K. V. 2007. Commercial Crops Technology. New India Publishing Agency, New Delhi, 480p.

CDB. 2003. Statistics - Coconut Development Board. *Indian Cocon.J.* 32:30

Gopakumar, C. S. 2011. Impacts of climate variability on Agriculture in Kerala. PhD thesis, Cochin University of Science and Technology, Cochin, 286p.

Krishnakumar, K. N. 2011. Coconut phenology and yield response to climate variability and change. PhD thesis, Cochin University of Science and Technology, Cochin, 241p.

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

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., 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., 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. 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.

Rajagopal, V., Kasturi, B. K. V. and Kumar, N. S. 2002. Drought management in plantation crops. In: Plantation Crops Research and Development in the New Millenium. Rethinam, P., Khan, H. H., Reddy, V. M., Mandal, P. K. and Suresh, K. (eds.), Coconut Development Board, Kochi. pp. 9-22.

Rajagopal, V., Shivashankar, S. and Jacob M. 1996. Impact of dry spells on the ontogeny of coconut fruits and its relation to yield. Plantation Research and Development 3(4): 251-255.

Rethinam, P. 1987. Management of drought situation in coconut plantation. *Indian Cocon. J.* 18: 3-5.

Appendix I

Monthly maximum temperature during 1999-2007

Month	Year								
	1999	2000	2001	2002	2003	2004	2005	2006	2007
January	32.4	32.9	32.6	32.8	33.3	33.4	33.2	34.3	32.5
February	34.5	33.3	34.5	34.3	34.7	35.2	35.1	34.8	34.0
March	35.5	35.6	34.8	36.3	34.6	36.5	35.7	33.4	36.0
April	33.4	34.0	34.2	35.0	34.6	34.8	33.7	31.8	35.7
May	30.7	33.7	32.3	32.6	34.0	30.4	33.6	29.9	32.8
June	29.5	29.6	29.3	30.0	30.9	29.6	29.9	29.5	30.1
July	28.4	29.8	29.0	29.8	29.5	29.3	28.7	29.8	28.4
August	29.8	29.1	29.3	28.9	30.0	29.5	29.9	29.6	29.0
September	31.6	30.7	30.8	31.1	30.9	30.8	29.4	31.0	29.4
October	30.5	30.7	30.7	30.8	30.8	31.4	31.0	31.7	30.5
November	31.4	32.2	31.6	31.8	31.5	31.1	30.7	31.5	31.7
December	31.6	31.1	31.3	32.3	32.2	32.1	31.5	34.3	31.6

Appendix II

Monthly minimum temperature during 1999-2007

Month	Year								
	1999	2000	2001	2002	2003	2004	2005	2006	2007
January	21.5	23.2	23.2	22.7	22.8	22.3	22.6	22.6	22.0
February	23.3	22.8	22.9	23.0	23.6	22.5	22.3	22.3	22.2
March	24.5	23.8	24.0	24.1	24.1	24.2	24.6	23.8	24.4
April	25.6	24.6	24.7	24.8	25.0	25.2	24.8	24.7	25.0
May	24.8	24.4	24.5	24.5	25.5	23.6	25.0	24.3	24.7
June	23.0	22.8	23.1	23.3	23.8	23.1	23.5	23.6	23.5
July	22.9	22.5	22.7	23.1	22.9	23.0	23.0	23.3	22.9
August	23.7	22.6	23.1	22.9	23.4	23.1	23.3	23.1	22.8
September	23.4	23.0	23.2	23.0	22.6	23.6	23.3	23.0	22.9
October	23.2	22.7	23.0	23.2	23.1	23.4	23.2	23.0	22.5
November	22.8	23.1	23.1	23.4	24.0	23.6	22.9	23.7	21.7
December	22.7	22.0	22.2	22.1	22.0	22.6	22.1	23.6	22.7

Appendix III

Monthly bright sunshine hours during 1999-2007

Month	Year								
	1999	2000	2001	2002	2003	2004	2005	2006	2007
January	9.3	9.2	8.0	8.1	9.4	9.6	8.2	9.0	8.7
February	9.1	8.6	8.0	8.4	9.2	9.6	10.0	9.6	9.8
March	11.1	9.7	8.1	8.2	8.5	8.6	8.8	7.6	8.2
April	6.2	7.2	6.5	7.8	7.5	7.4	7.1	7.1	7.7
May	4.9	8.5	6.4	5.8	6.3	3.4	7.0	5.8	6.6
June	5.0	3.2	2.3	2.7	4.0	3.4	3.1	3.8	3.5
July	2.4	4.8	2.4	3.4	2.5	2.1	1.7	2.1	0.7
August	5.4	3.1	3.6	3.1	4.2	4.4	5.2	4.3	3.2
September	7.1	6.0	5.3	7.8	7.3	5.1	4.4	3.9	2.5
October	4.8	5.6	4.7	4.4	5.6	6.0	5.2	4.8	4.4
November	8.2	9.2	6.8	6.3	7.1	7.1	5.2	6.5	8.0
December	8.8	7.9	8.1	8.7	9.1	8.9	7.3	7.8	6.7

Appendix IV

Monthly rainfall during 1999-2007

Month	Year								
	1999	2000	2001	2002	2003	2004	2005	2006	2007
January	0.0	0.0	0.0	0.0	0.0	0.0	7.6	0.0	0.0
February	22.8	4.6	12.2	0.0	162.1	0.0	0.0	0.0	0.0
March	0.0	0.0	4.4	16.3	94.8	8.6	0.0	95.2	0.0
April	39.0	67.9	243.1	50.8	23.8	60.2	171.4	86.2	61.0
May	430.5	1[illegible]7.2	192.6	308.4	40.3	578.7	89.2	675.5	240.5
June	500.2	602.0	676.2	533.5	570.6	786.0	711.4	608.6	826.4
July	823.3	353.8	477.7	354.2	492.6	369.6	727.5	519.0	1131.6
August	260.1	518.8	256.2	506.6	490.1	386.9	346.5	550.6	549.7
September	28.4	198.1	206.1	124.0	53.7	208.8	416.1	522.2	765.9
October	506.2	262.2	215.4	387.7	276.8	492.3	178.4	323.7	383.8
November	9.1	41.3	116.2	22.1	18.2	71.7	11.6	79.3	24.8
December	0.0	13.4	0.0	0.0	0.0	0.0	3.2	0.0	8.7