CROP WEATHER RELATIONSHIPS OF COCOA
(*Theobroma cacao* L.)

By

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DECLARATION

I, **N. Manikandan** (2006-11-133) hereby declare that this thesis entitled **'Crop weather relationships of cocoa (*Theobroma cacao* L.)'** is a bonafide record of research work done by me during the course of research and this thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

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Certified that this thesis, entitled **'Crop weather relationships of cocoa (*Theobroma cacao* L.)'** is a record of research work done independently by **Mr. N. Manikandan** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to him.

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We, the undersigned members of the advisory committee of **Mr. N. Manikandan**, a candidate for the degree of **Master of Science in Agriculture**, with major field in **Agricultural Meteorology**, agree that the thesis entitled "Crop weather relationships of cocoa (*Theobroma cacao* L.)" may be submitted by **Mr. N. Manikandan** in partial fulfillment of the requirement for the degree.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF PLATES

Introduction

1. INTRODUCTION

The global production of cocoa is around 36.49 lakh tonnes against the demand of 37.37 lakh tonnes. Ivory Coast leads in cocoa production in the World with a contribution of 38 per cent, followed by Ghana and Indonesia. Unlike in other crops, it appears that the production and demand of cocoa at the global level match each other to a large extent. However, the recent trends in the world production of cocoa beans indicated that there was a drop of nine per cent in 2006-07, declining from 3.8 million tonnes in 2005-06 to 3.4 million tonnes in 2006-07 (Table.1). It was attributed to unfavourable weather conditions in many cocoa producing areas. West Africa, the main cocoa producing region, was hit by a severe harmattan (dusty dry wind from November-March) and its inherent dry weather, which lasted from the end of 2006 to February 2007, had a strong

Table.1. Global production of cocoa beans

Countries	Production in '000 tonnes		
	2005-06	2006-07	2007-08 (estimates)
Cote d'Ivorie	1408	1229	1380
Ghana	740	615	700
Indonesia	560	530	480
Nigeria	200	190	200
Cameron	169	168	200
Brazil	162	126	165
Ecuador	114	115	113
Others	413	407	408
Total	3766	3380	3649

Source: ICCO Quarterly Bulletin of Cocoa Statistics, Vol. XXXIV, No.3, Cocoa year 2007/08

negative impact on global cocoa production. In Asia and South America, El Niño- related weather conditions developed in September 2006 and continued until the beginning of 2007. It led to relatively low cocoa production in 2006-07. However, it was rebounced in 2007-08 to some extent though it was low (36.49 lakh tonnes) when compared to that of

2005-06. The favourable weather which prevailed over most of the cocoa growing regions during 2002-03 and 2003-04 helped to achieve better production during the above years while dip in global production in 2006-07 due to unfavourable weather. It reveals that the weather abnormalities like floods, droughts, cold and heat waves across the cocoa growing regions of the world adversely affect the cocoa production and the cocoa industry is likely to suffer. Therefore, there is need to understand the effect of weather on reproductive phase of cocoa so as to manipulate the crop for sustenance of cocoa yield through better management practices.

Cocoa (*Theobroma cacao* L.), a beverage crop native to Amazon region of South America, has been introduced in India as profitable mixed crop in coconut and arecanut plantations in 1960s. The crop is now cultivated in an area of 31,885 ha with an annual production of 10560 tonnes and productivity of 535 kg/ha in India (Table.2). Comparing

Table.2. Area and production of cocoa over India

Year	Area (ha)	Production (T)	Productivity (kg/ha)
2002-03	21893	8397	560
2003-04	24665	9040	500
2004-05	27811	9250	515
2005-06	27811	9500	530
2006-07	32360	10180	550
2007-08	31885	10560	535

Source: Directorate of Cocoa and cashew Development, Kochi

this to the global production of 36.49 lakh tonnes, India is no way nearer to the global situation. India’s annual cocoa demand was pegged around 18,000 tonnes during 2007-08. The declining trend noticed in global production during 2006-07 was not seen in India, rather there was an increase (550kg/ha) in cocoa productivity in 2006-07. The productivity of cocoa was low (500kg/ha) in 2003-04 despite increase in area and no improvement since last five years was seen in terms of cocoa productivity. Like other crops, there was stagnation in cocoa productivity due to weather aberrations like floods and droughts as cocoa is sensitive to waterlogging as well as soil moisture stress. It is presumed that the low productivity in 2003-04 could be attributed to high summer temperature in 2004 over Kerala due to prolonged drought and heat wave that occurred in Andhra Pradesh and other southern states during 2003. Kerala ranked first in production, accounting for 33 per cent of area and 57 per cent of the production in India. Karnataka, Andhra Pradesh and Tamil Nadu are the other cocoa growing states. The crop is now cultivated in an area of 10530 ha with an annual production of 6000 tonnes and productivity of 680 kg/ha. Unlike a narrow gap between global demand and production, the gap between cocoa demand and production is very high (41 %) at the national level. It could be attributed to low productivity as well as relatively less area under cocoa with bearing trees as cocoa had experienced the market crisis during early 1970s, 1980s and 1990s during which most of the cocoa plantations were cut and removed. One of the factors attributed to low cocoa production is due to weather aberrations like occurrence of floods and droughts in addition to high summer temperature leading to heat waves.

The plant needs equitable climate with well distributed rainfall. It requires an annual rainfall of 1500-2000 mm with a minimum of 90-100 mm rainfall per month. In majority of the regions, where cocoa is cultivated, a high but often unevenly distributed annual rainfall occurs resulting in fairly well defined dry and wet seasons each year. These seasonal changes exert marked effects on the growth of the cocoa tree, and on its cycle of flushing, flowering and fruiting. Cocoa flowers throughout the year though it varied highly between the months. The peak period of cocoa flowering varied depending upon the location. It is reported that the peak period of flowering in Ghana, Cuba, South America and India was seen during April-June, June-September, October – May and November-May, respectively (Fig.1). Cocoa flowering and pod set decide the output of cocoa. The optimum temperature range for cocoa varies from 21.1°C to 32.2°C, with a mean monthly minimum of 15°C as the lower limit and an absolute minimum of 10°C. However, there is evidence that somewhat lower temperature can be tolerated. It is reported that the humidity above 85% is the optimum for growth. Shade studies on Cocoa indicated progressive increase in yield (with the use of chemical fertilizers) and progressive decrease in vegetative growth with decreasing levels of shade (Nair *et al*., 1996).

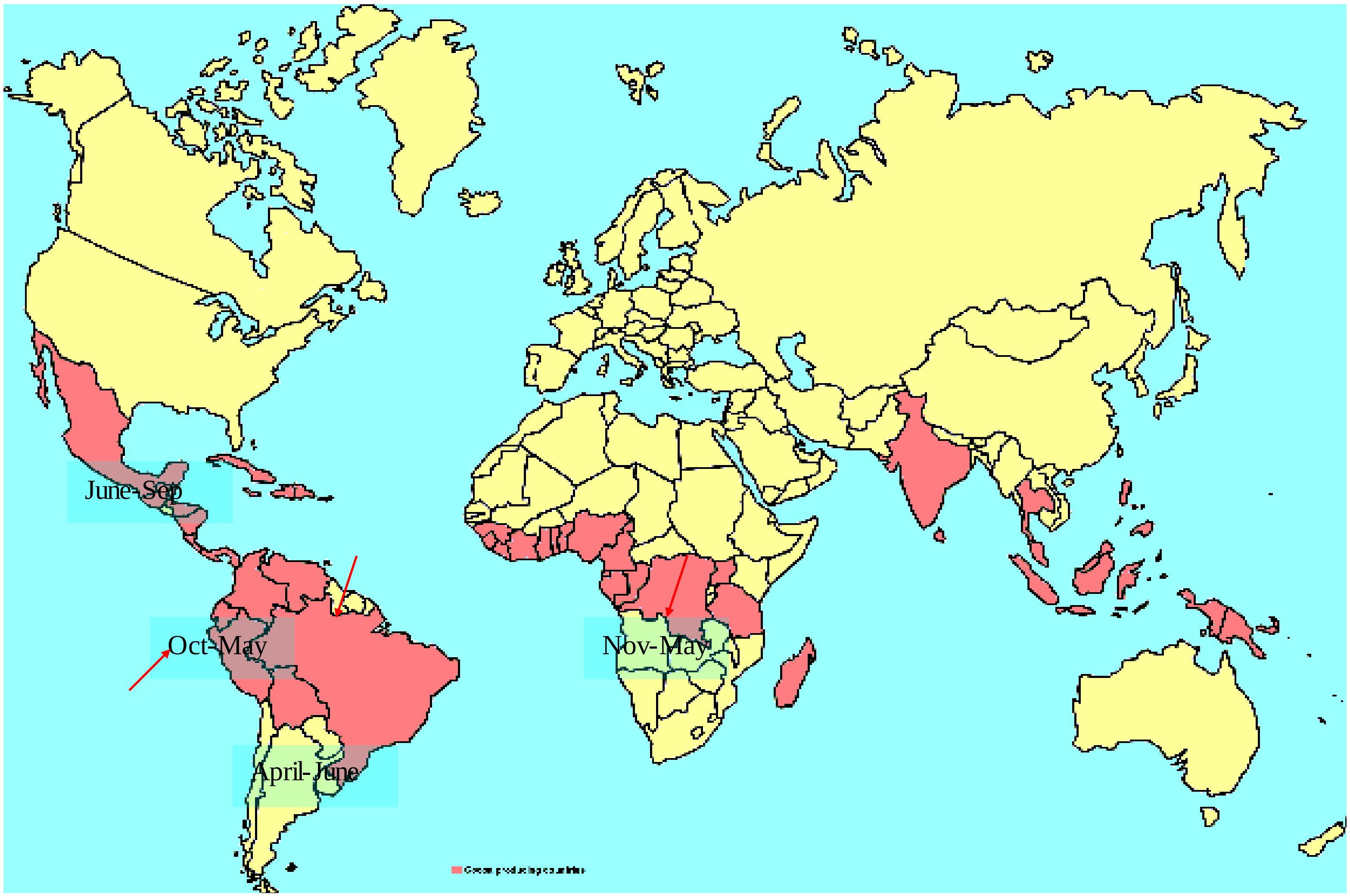


Fig.1. Cocoa growing regions over the world and peak period of flowering

Cocoa seeds are the source of commercial cocoa (cocoa beans), the four intermediate cocoa products (cocoa liquor, cocoa butter, cocoa cake and cocoa powder) and chocolate. Although the market for chocolate is the largest consumer of cocoa in terms of bean equivalent, intermediate products such as cocoa powder and cocoa butter are used in several areas. Cocoa powder is essentially used as flavour in biscuits, ice cream, dairy drinks and cakes. Apart its use as flavour it is also used in the manufacture of coatings for confectioners or frozen desserts. Cocoa powder is also consumed by the beverage industry for example for the preparation of chocolate milk. Besides the traditional uses in chocolate manufacture and confectionery, cocoa butter is also used in the manufacture of tobacco products, soap and cosmetics. It is also a folk remedy for burns, cough, dry lips, fever, malaria, rheumatism, snakebite and wounds. It is reported to be antiseptic and diuretic.

Looking at the industry needs for various purposes, there is a heavy demand for cocoa. At present, the gap between supply and demand in cocoa appears to be more at the national level. To fill the gap, various agro-technologies and crop improvement strategies are to be chalked out, for which the response of crop to various environmental factors are to be understood. Weather aberrations during the flowering and fruiting result in the final cocoa production. Therefore, it is important to understand the effect of weather on flowering and fruiting pattern of cocoa to minimise the crop losses against the weather abnormalities. Though it is known that cocoa yield is highly variable and sensitive to various weather factors, the studies on crop weather relationships in cocoa are relatively scarce. Hence, the present experiment was undertaken to understand the effect of weather variables on flowering, fruit set and final yield of cocoa with the following objectives:

- To study the seasonal influence on flowering and fruiting behaviour of cocoa
- To find out the relationship between weather elements and cocoa productivity
- To understand the impact of climate variability on cocoa production across the State of Kerala

Review of Literature

2. REVIEW OF LITERATURE

2.1. Climatic requirements of cocoa

The climatic conditions of cocoa growing areas vary from one location to another still, they fall in the tropical range. The vegetative and reproductive growth of cocoa is influenced by a complexity of environmental factors, particularly rainfall and temperature.

2.1.1. Rainfall

Adams and Mc Kelvie (1955) observed that most of the cocoa growing areas had a short, mild, dry season. In Ghana, cocoa was limited to those areas which receive more than 250 mm of rain in the dry period between November and March. Ochse *et al*. (1961) reported that an annual total of 1500-2000 mm is needed without irrigation for better growth. According to Cautrecasas (1964, 1984) cocoa flourished where rainfall ranged between 2000 and 3000 mm with more or less even distribution throughout the year. In most regions where cocoa is cultivated a high but often unevenly distributed annual rainfall occurs, resulting in fairly well defined dry and wet seasons each year. These seasonal changes exert marked effects on the growth of the cocoa tree, and on its cycle of flushing, flowering and fruiting (Sale, 1970). Purseglove (1974) has estimated the rainfall in cocoa growing areas to be 1010 to 2540 mm. It is also stressed the importance of distribution of rainfall and stated that there should be rainfall of 101 mm or over per month and a marked dry season with less than 63.5 mm per month should be absent.

Wood (1985) reported that the total annual rainfall in most of the cocoa growing countries is between 1250 and 2800 mm. In West Africa, this varied from 1200 to 3000 mm while in South America rainfall was more than 2000 mm per annum. Malaysia and Papua New Guinea of South-East Asia show a far more uniform climate with well distributed rainfall and with no dry months. It was concluded that the distribution of rainfall is more important than the total annual rainfall. Brenes *et al*. (1988) defining areas with cocoa growing potential, reported that precipitation of 1600 – 3200 mm per year is highly suited for growing cocoa. Asopa and Narayanan (1990) described well distributed rainfall above 1200 mm a year as the most conducive for growth.

For ensuring best growth of cocoa, proper distribution of rainfall is considered more important than the total amount. In most of the major South American, African and Southeast Asian cocoa producing countries, distribution is more or less even with minor peaks. It is so well distributed that around 10 cm of rain is received almost every month (Nair *et al*. 2002). The plant needs equitable climate with well distributed rainfall. It requires an annual rainfall of 1500-2000 mm with a minimum of 90-100 mm rainfall per month (ICAR, 2002).

2.1.2. Temperature

The optimum temperature range for cocoa varies from 21.1 ^{o}C to 32.2^{o}C, with a mean monthly minimum of 15^{o}C as the lower limit and an absolute minimum of 10^{o}C as reported by Erneholm (1948). However, there is evidence that somewhat lower temperature can be tolerated. In the State of Sao Paulo, cocoa has been planted in places where the mean monthly minimum in the coldest month is about 10^{o} C and the absolute minimum drops to 4^{o}C to 6^{o}C (Alvim, 1977). Lee (1974) reported that in Malawi (13^{o} 3'S and 34^{o}E) where the minimum temperature is 13^{o}C to 14^{o}C for three months, cocoa has been grown successfully giving yields up to 2000 kg/ha, but when the temperature fell to 10^{o}C for several consecutive days yields were reduced by about 50 per cent. According to Wood (1985), a minimum range of 18^{o}C to 21^{o}C and a maximum of 30^{o}C - 32^{o}C limited the cocoa belt. It is also noted that number of flowers increased as the temperature increased. Brenes *et al*. (1988) described mean temperature between 24^{o}C and 29^{o}C as the best temperature range for commercial cocoa growing areas. Asopa and Narayanan (1990) reported a shade temperature between 13^{o}C and 35^{o}C as the optimum range for growth. Temperature decides the number of pods carried to maturity, pod size and bean characters (Nair *et al*., 2002). The optimum range of mean monthly temperature of cocoa growing region is 15-32^{o}C. The absolute minimum temperature for any responsible period should be 10^{o}C, below which frost injury takes place. However, cocoa grows and produces well in plains with more moderate temperature (ICAR, 2002).

2.1.3. Relative humidity

According to Wood (1985), relative humidity is uniformly high in cocoa growing areas, often 100 % at night, falling to 70 to 80 % by day, and sometimes lowers during dry season. Asopa and Narayanan (1990) reported that the humidity above 85% is the optimum for growth.

2.1.4. Shade

Freeman (1929) in the earliest recorded field experiment to determine the optimum degree of shade for cocoa, reported that lightly shaded cocoa gave the highest yield. Humphires (1943) observed that shading influenced the canopy temperature of cocoa and when the mean weekly maximum temperature in the canopy dropped below 28.3^{o}C no flushing took place. Greenwood and Posner (1950) and Smith (1964) also reported similar results. Evans (1951) described a shade experiment in which cocoa was grown under different artificial shade viz, 15 %, 25 %, 50 % and 100 % of day light. Results during the 1st year showed that the cocoa made the best growth at 25 to 50 % sunlight but plants receiving 50 % were better shape. As plants became bigger and auto shading developed the 75 % light plot improved its position, with increasing light intensity, the need for N fertilizer became more apparent. The removal of shade trees may affect not only light intensity but also other environmental factors such as air movement and humidity and soil temperatures, and under some conditions shade trees are considered to provide an essential buffering action against the deleterious effects of sudden and extreme environmental fluctuations (Evans and Murray, 1953). Overall flower production is considerably higher in the sunny habitat than in the shaded habitat (Young, 1983).

Intense shade generally decreases the flowering in cocoa. A sudden burst of flowering was seen when the shade trees becomes deciduous during the dry season (Young, 1984). Watt (1986) stressed the importance of shade and moisture for the better growth of cocoa seedlings and reported that young cocoa seedlings must be shaded and well watered. The shade levels at which cocoa was cultivated had been highly variable.

The studies conducted by Nair *et al*. (1996) at the KAU on the response of cocoa to shade indicated that the girth of the stem and yield increased with increase in illumination levels. The results suggested that it is possible to cultivate cocoa without shade under Kerala conditions and that the productivity will be the highest under shade free situations. However, shading may be necessary in the early years using temporary shade plants.

Alternatively, full-sun production results in increased yields in the short term but requires the use of chemical fertilizers to maintain high yields (Ahenkorah *et al*. 1974 as cited in Rice and Greenberg (2000). A survey of the farmers' farms has indicated that most of the cocoa received about 40% incident light, the range is being 30-80%. The experiment conducted in different cocoa growing countries indicated that the shade requirements of young cocoa plants is as much as 75% which can be gradually brought down to about 25% when cocoa comes to production (Nair *et al*. 2002). Although some farmers are switching to full sun production, many farmers acknowledge the benefits of maintaining shade in production. For example, benefits that Ecuadorian farmers attribute to shade include maintaining soil moisture, improving soil fertility and weed suppression (Bentley *et al*. 2004).

2.2. Flowering behaviour

Hewison and Ababio (1929) conducted studies on the flowering pattern of cocoa in Ghana and reported that the period from March to July was the time of main flowering activity with the greatest number of flowers produced from April to June. It was also stated that only 0.2 to 1.5 per cent of cocoa flowers developed into mature fruit. Similar results were reported by Purseglove (1974). Alvim (1965) reported that flowering in Bahia was most intensive during the early part of the rainy season, followed by July – September drought. The scarcity of flowers from June to September was attributed to the indirect effects of low temperature. The non-flowering period was July – September (Alvim, 1966). At the beginning of the wet season, there was a burst of flowers which resulted in the main crop after five to six months.

In unirrigated cocoa, the flowering pattern may be quite different and is limited usually to two seasons a year. In countries like Ghana and Nigeria where the rainfall is more evenly spaced, flowering was found throughout the year, though varietal variations existed (Amponsah, 1973, 1975, 1976). Abundant flowering occurred from June to September and gradually decreased thereafter. Under severe drought conditions, however, flowering decreased earlier and abruptly (Purseglove, 1974). According to Murray (1975), out of 10,000 flowers produced by a mature tree in a year, only 10 to 50 (0.1 to 0.5 per cent) developed to mature fruits. In Vittal (Karnataka), the annual flower production per metre of stem varied from 168 to 2358 (CPCRI, 1977). Rajamony (1981) and Madhu (1984) described the flowering pattern in Kerala as throughout the year.

Studying the flowering and fruit setting characters of upper Amazon cocoa, Uthaiah and Sulladmath (1984) observed that more than 75% flowers were produced between January and April with a peak in March (30.9%) in Bangalore. Cocoa produces a large number of flowers. Zacharias (1983) observed that the number of flowers per unit length of 50cm on the trunk ranged from 93 to 904 with a mean of 258 in Thrissur, Kerala. Under Dharward conditions, Bhat (1983) recorded 8000-10000 flowers per tree per year out of which only 3.7% of the flowers set fruits and only 16% of the set fruits matured. It is also observed that about 70% flowers were produced on the crown periphery, 22% on primary branches and 8% on the trunk. Madhu (1984) reported that the mean of 7062 flowers per tree per year under Kerala conditions was noticed from November to April. It is also noted that the recovery of mature pods ranged from 21.6 to 44.7% of the pollinations made and 29.6 to 63% of the pods set.

2.3. Fruiting behavoiur

Alvim (1974) studied the pattern of climate and cropping of cocoa in Bahia and West Africa. In Bahia where the rainfall was fairly well distributed, the cocoa harvest season was found to be rather long, usually starting in April and extending until mid January. The April to August crop was bigger than the September to January crop, depending on the rainfall pattern. During the years with well distributed rainfall, both the crops had almost the same volume. In West Africa, where a long dry season exists from

October-November to March-April, about 80-90% of the crop was harvested in a relatively short period between September and December.

Two peaks of harvest are observed in most of the cocoa growing countries during the rainy season and again during the dry season. In countries with marked wet and dry season, the main harvest occurred five to six months after the start of wet season, as reported by Bridgeland (1953) and Alvim (1967). Purseglove (1974) observed that the cocoa plants produced pods throughout the year, but the main harvest usually began at the end of the wet season and continued for a period of three months. In West Africa, the main harvest was from October to January while February to March in Trinidad, followed by a minor harvest early in the rainy period. Monthly flower production and fruit setting varied from tree to tree. Flowering production was heavy during December to May, and then decreased, reaching minimum during August – September. In general, there were two peak periods of flowering; one in April – June and the other in December to February. The peak period of flowering was in May, and the peak period of fruit setting was in March and October. Fruit set was generally more during the dry months from December to June, and very low or absent during July – September. The mean annual fruit set was only 3.0% and out of this one fourth reached maturity (Ravindran, 1980).

Fruiting pattern of irrigated cocoa in Nileswar, Kerala was studied by Hassan *et al.* in 1981. The peak cropping months were July, August, June and October, which together accounted for 78% of the total annual yield. The least production months were January, December, February and March in that order. The yield during these months was 3%. In upper Amazon cocoa, Uthaiah and Sulladmath (1984) found that more than 60% of the yield came from fruits set during January and February. Wood (1985) also showed that there were one or two peak harvest periods and there was some cocoa to be harvested at all times of the year. He also reported that in Ghana, on an average, 25% of the crop was harvested in the peak month, November, which was about six months after wet season began. In Malaya, where there was no true dry season, the peak of harvest was less pronounced with 20 to 25% of the crop in the peak, which falls between November and March.

Bopiah and Bhat (1989) recognized two peaks of harvest, April to July (71%) and November to December (17.8%). The wet season (June to August) accounted for 42.8 per cent and the remaining 57.3% was harvested during dry period. In Karnataka, Jose (1996) compiled the yield data on quarterly basis. It is found that on an average 40% of the fruits was harvested during June to August, 30% between March and May, 16% between September and November and the remaining 14% between December and February.

2.4. Pod and bean characters

Seasonal differences in bean characters have been reported by many workers. Egbe and Owolabi (1972) found lowest bean weight, lowest butter fat and highest shell percentage for the February – May crop in Nigeria and highest bean weight, highest butter fat and lowest shell percentage for the October – January crop. According to Manurung et al. (1988), the number of rainy days, evening temperature and wind speed occurring seven months earlier together contributed 66.9% of the variation in bean fresh weight. Bopiah and Bhat (1989) analyzed the bean characters with regard to weather conditions and found higher pulp percentage and lower total soluble solids and bean weight in wet season as compared to dry season.

2.5. Fruit load and flowering

The fruit load of plants also affects flowering intensity, there being a decrease in flowering during intense fruit development period. Hewison and Ababio (1929) observed that in Ghana where less than one third of a tree's crop was set by the end of April, great flowering activity occurred during June. Hutcheon *et al*. (1973) observed that in regions where there is pronounced seasonal variations in flowering, the period of low flowering invariably occurs when the plants have the highest fruit load.

Alvim *et al*. (1972) attributed this effect to the competition between fruits and flowers for a substance or substances (which could be Carbohydrates) whose contribution is related to flowering intensity. Alvim in 1974 and 1981 again stressed the importance of fruit load on flowering. Alvim (1984) reported that the flowering intensity showed marked increase by manual removal of the fruits in the tree. Mossu and Lotode (1977) reported that the presence of fruits had a negative influence on fruit set. Fruit setting seems to be inversely related to flower production. The trees with high flower production gave low fruit set, while trees with low flower production and gave better fruit set. The profuse flowering is more a wastage of energy on the part of the tree than an advantage (Ravindran, 1980).

2.6. Weather and cocoa

2.6.1. Rainfall / soil moisture

2.6.1.1. General growth

Greenwood and Posnette (1950) from their studies on cocoa reported that flushing was controlled by an endogenous system inherent in the plant, but at least after the tree had passed the juvenile stage, its onset was affected by environment. It is also observed that growth of cocoa occurred in the dry month while during wet season, when condition of rainfall and humidity were more stable, little growth occurred. Irrigation had not affected the frequency of flushing of individual trees. All the trees, irrespective of treatment difference, flushed at more or less regular intervals of eight to ten weeks. Container experiments involving watering regimes have generally demonstrated the beneficial effects of wetter treatments on growth (Murray, 1966; Sale, 1970). Alvim (1959) reported that where rainfall was adequate and the dry season was not very severe or prolonged, irrigation seemed to have only a small effect on mature cocoa. Alvim (1960) showed that the stomata of container grown cocoa plants started to close when the available moisture fell to 70 % and closed rapidly as available moisture fell from 50 to 25 per cent. Murray (1961) working on older trees in Trinidad found irrigation to be beneficial in only one year out of five studied. Clearly, there will be variations in the severity of dry seasons, but in the case of established trees, there may be a long period during which adaptation to a new soil moisture regimes takes place. Smith (1964) studied the effects of irrigation on young cocoa in Ghana where he found favourable responses in terms of flower production and growth rate.

The effect of soil moisture on seedling growth was studied at the Cocoa Research Institute, Ghana (CRI, 1972). The experiment was conducted in a greenhouse where plants were grown in top soil in five litre buckets. Between 11 and 44 weeks, these plants were subjected to eight different soil moisture regimes, there being ten plants in each. The soil moisture content was allowed to fluctuate between field capacity and one of the following soil moisture percentages – 100, 90, 80, 70, 60, 45, 30 and 15 per cent. The soil moisture was determined by weighing bucket + soil + plant as necessary and rewatering to field capacity when the appropriate degree of drying has been reached. Under the conditions of the experiment, growth was the best when the soil was allowed to dry out to about 60 per cent of the available moisture. There is little doubt that the plants growing in regimes wetter than this suffered from poor root aeration and probably reduced water and mineral uptake. The results emphasise that excess soil moisture is as harmful to the growth of cocoa seedlings as inadequate moisture. This is especially true where the soil is rich in organic matter and has a high water retaining capacity. Studies of the fine changes in stem diameters of seedlings using the dendrograph also suggest that stem growth is slower during the day following watering than during a day when the soil has begun to dry out.

Balasimha (1988) conducted studies on the behaviour of cocoa under drought conditions, found that the relative water content of leaves of rainfed cocoa plants was lower than that of irrigated plants. This was accompanied by a decrease in leaf water potential and osmotic potential. As drought progressed, nitrate reductase activity and chlorophyll content declined while proline accumulated in the leaves. Leaf elongation rates were inhibited under drought and there was a significant difference in total dry matter produced, canopy area, relative growth rate and net assimilation rate. It was suggested that for cocoa the ability to tolerate drought resulted from stomatal regulation, which reduced transpirational water loss and high tissue elasticity. Patchy rains helped maintain good growing conditions for cocoa in Ivory coasts main growing regions over the last week after a fortnight of dry weather. It is reported that these showers will boost the development of small pods which were due to ripen before the end of October-March main crop (WCF, 2007b).

2.6.1.2. Flowering

Smith (1964) conducted a study on the effect of three soil moisture regimes on young Amazon cocoa in Ghana. It is found that irrigation increased growth rate and flower production, but did not affect the percentage of setting or wilting of cherelles. It is also observed that irrigated trees flowered earlier and produced greater number of flowers than did the unirrigated trees, probably because of the increased size of irrigated trees and large number of cushions available for flower production. Alvim (1968) described excessive rainfall with waterlogging from September 1967 to March 1968 and lower than average temperature as the reasons for reduced flowering during the season. Sale (1970) obtained profuse flowering in potted cocoa plants whenever the soil was watered following a period of moisture stress and concluded that flower initiation has been enhanced during the dry period and only flower growth was inhibited by moisture deficiency. Based on the results of previous experiments, Alvim *et al*. (1972) also opined that periods of increased flowering were usually preceded by a relatively dry period followed by a wet period and that decreased flowering was associated either with a dry spell or a excessive soil moisture. Hutcheon *et al*. (1973) showed that irrigation increased flower production of both the unshaded as well as shaded cocoa but this effect was great in unshaded trees. Hutcheon (1977) recorded maximum flowering and fruit setting after the beginning of the wet season, when both leaf area and photosynthetic rate were high.

Describing flowering and fruit setting patterns of cocoa trees at three localities in Costa Rica, Young (1984) reported a marked decline in flowering near the end of the rainy season when rainfall was very high. In Kerala, Madhu (1984) found that the mean monthly rainfall one month prior to flowering along with temperature and sunshine determined the flower production. The cocoa tree needs a high and well distributed rainfall, possibly a short dry spell to stimulate flowering (Balasimha, 1999).

2.6.1.3. Fruiting

Studying the flowering and fruiting characters of cocoa in relation to weather elements, Couprie (1972) reported that fruit set was strongly influenced by the rainfall which occurred four to twelve weeks earlier. Boyer (1974) also reported a positive relation of fruit set to rainfall. Mossu and Lotode (1977) reported that rain was unfavourable for pollination. According to Alvim (1981), yield variability from year to year was more affected by rainfall distribution than any other climatic factor. Studying the fruiting pattern of irrigated cocoa in Kerala, Hassan *et al*., (1981) observed a significant correlation between the number of harvested pods and number of rainy days. Heavy rains during dry season in Ivory Coasts resulted in pod rot and helped fungal black disease to spread (COPAL Cocoa, 2007a).

2.6.1.4. Yield

A highly significant negative correlation is shown between yield and rainfall (Fowler *et al*. 1956, Gordon, 1976). Ali (1969) in Ghana found a positive correlation between yield and rainfall at some times of year and a negative correlation at others. In the case of cocoa, Alvim (1977) reported that seasonal variations in yield is more pronounced in regions where there is marked seasonal variations in climatic factors like rainfall. Correlation coefficients of number of rainy days of previous year (23rd fortnight) found significant with cocoa yield (Vijayakumar *et al*., 1991).

2.6.2. Temperature

2.6.2.1. General growth

Humphires (1943), working in Trinidad, concluded that flushing was largely controlled by temperature, and suggested that the weekly mean of the daily maximum temperature must be at least 28.3^{o}C for flushing to be initiated. A similar conclusion was reached by Greenwood and Posner (1950) in Ghana. However, Alvim (1957), from studies made in Costa Rica, suggested that leaf flushing was more closely connected with the mean diurnal temperature range, and that a difference between day and night temperatures of at least 9^{o}C was necessary for flushing to occur. Murray and Spurling (1964) reported that in Trinidad a constant temperature of 31^{o}C leads to loss of apical dominance, the auxiliary buds producing numerous flushes with small leaves. However, Wood (1985) noticed that such conditions do not occur in the field where there will be diurnal variation, and cocoa trees can withstand temperature well above 31°C for short periods during the day. Sale (1968), reported that plants grown at a constant temperature of 23.3°C produced the fewest flushes, those at a constant of 30°C produced the most. While an increase in either day or night temperature increased the number of flushes, an increase in day temperature had the greatest effect. Leaf surface temperature of 46°C was commonly observed in Trinidad with a maximum of 52°C (Hoskin and Sale, 1969). Temperature as high as above 50°C will eventually damage the leaves, but in the field it is unlikely that leaves will be subjected to such temperature for long enough to cause damage. In the case of cocoa, Alvim (1977) reported that the variation in yield is more pronounced in regions where there is marked seasonal difference in climatic factors like rainfall, temperature and sunshine hours. Harun and Hardwick (1988) found that photosynthetic rates changed very little between 20°C and 30°C. Stomatal resistance, however, decreased with increase in leaf temperature.

2.6.2.2. Flowering

Alvim (1965, 1968, 1981) reported that temperature affects the flowering intensity and lower than average temperature contributed to reduced flowering. Flowering was inhibited when the monthly mean temperature was below 23°C (Alvim, 1966). Sale (1969) studied the flowering process of cocoa in relation to the temperature conditions in Trinidad, West Indies. It is observed that as compared to plants growing in regions with a day temperature of 23.3°C, plants in the regions with a day temperature of 26.6°C to 30°C had more active flowering cushions per plant and more number of flowers per cushion per week. Couprie (1972) showed that flowering was greater when daily temperature variation was least. Mossu and Lotode (1977) found low temperature to be favourable for pollination. Madhu (1984) noted that the mean monthly minimum and maximum temperature, one month previous to flowering affected the flower production. Wood (1985) also reported the effect of temperature on flowering. He found that number of flowers increased as the temperature increased. Flower production was positively correlated with maximum temperature and in the case of minimum temperature both positive and negative correlations were observed (Prameela, 1997).

2.6.2.3. Yield

Couprie (1972) examined the growth, flowering and fruiting characters of cocoa and found that the fruit set was negatively influenced by the cumulative maximum temperature of the proceeding two weeks. Boyer (1974) also reported a negative relation of fruit set to temperature. Alvim *et al.* (1972) studied pod development in relation to temperature and concluded that the rate of pod development increased with increase in temperature.

Regarding seasonal distribution of the crop, Alvim (1981) reported that temperature played an important role in regions like Bahia where there is marked seasonal difference in temperature. Hassan *et al.* (1981) observed a significant positive correlation between the number of harvested pods and mean monthly maximum temperature five months before. Alvim (1987) reported that in Bahia, the relatively low temperature from June to August was responsible for the lack of harvest from January to March, that is seven months after the cool period (mean temperature lower than 23^{o}C). Vijayakumar *et al.* (1991) observed that the maximum temperature of fourth and 21st fortnight had significant effect on yield. Studies conducted by Amma *et al.* (2005) indicated that a decline of 39% in annual yield was recorded during 2004 due to the disastrous summer drought when compared to 2003. It might be due to a sudden rise in maximum temperature of the order of 2-3^{o}C from 14th January to 16th March 2004 when compared to that of normal maximum surface air temperature (33.0-36.5^{o}C) during the above period. The study also revealed that there was a lag period of four to five months between the occurrence of adverse weather and monthly pod yield of cocoa.

2.6.3. Humidity

The effect of humidity on cocoa plants was studied by Sale (1968). The most marked effect was on leaf area, plants growing at low humidity (50 – 60%) having larger leaves and greater leaf area than plants growing at medium (70 – 80%) and high (90 – 95%) humidity. Excess humidity (> 90%) also affects the yield (Williams and Chew, 1979). Plants at the low humidity flushed before the others, but thereafter the period between flushes was rather longer at low and medium than at high humidity (Sale, 1970).

Gomes *et al*. (1987) reported that the stomata of three month old seedlings were more open at high relative humidity (76 – 89%) than at low relative humidity (39 – 62%). In both regimes, stomato closed gradually during the day, with the rate of closure accelerating in the late afternoon. Transpiration rate was correspondingly high early in the day and low late in the day. Average leaf diffusive resistance (rl) was 26 % lower at high relative humidity. Nonetheless, transpiration rate was generally higher for plants in the low RH, because of the much greater vapour pressure gradient between the leaf and air. Abruptly lowering the RH at noon rapidly increased diffusive resistance and increasing RH decreased diffusive resistance. In another experiment conducted in constant high or low RH regimes, diffusive resistance was lower, the rate of net photosynthesis was higher, leaf water potential (psi) was lower (negative), and transpiration rate was lower in the high RH regime. Water use efficiency was higher at high than at low RH. Thus, differences between transpiration rate and water use efficiencies at high at low RH were a direct result of variations in vapour pressure deficit between the two humidity regimes. Stomatal opening and closing reflected direct effects of humidity on guard cells rather than responses to changes in bulk leaf water potential. In addition, root to leaf hydraulic conductivity was apparently greater at low than at high RH.

Harun and Hardwick (1988) studied the effect of different temperature and water vapour pressure deficits on photosynthesis and transpiration of cocoa leaves. Infrared analyzers were used to measure photosynthesis and respiration. Photosynthetic rate remained constant with low water vapour pressure deficit to 10 m bar and thereafter (with increasing water vapour pressure deficit) remained constant. Stomatal resistance increased with any increase in water vapour pressure. The experiment conducted by Prameela (1997) showed that the both morning and evening relative humidity had a negative influence on flower production. In both the cases, maximum influence was noted eight weeks prior to flowering.

2.6.4. Sunshine

Soria (1970) studied the annual flowering and pollination of cocoa at two localities of tropical rainforest climatic conditions in Costa Rica. He found that the annual flowering and pollination could be represented as a bimodal curve in direct proportion to the bimodal regime of the solar energy. Couprie (1972) reported that sunshine had a negative but non-significant effect on fruit set and cherelle wilt. Boyer (1974) supported this theory. Madhu (1984) found that the mean monthly sunshine hours one month prior to flowering affected the flower production. The studies conducted by Prameela (1997) showed that the bright sunshine hours had positive influence on flowering and the maximum correlation was noted seven weeks before flowering. The cocoa needs a lot of sunshine with rains for the production of flowers and cherelles. Experts say cocoa trees require at least four hours of sunshine per day for the development of pods (WCF, 2007).

2.6.5. Wind

Cocoa yield is reduced by wind in Brazil, some parts of Ghana and Nigeria, (Alvim, 1977). The synergistic effect of wind and solar radiation cause severe mechanical injury at the pulvinus region (Alvim *et al*., 1972). Wind is an important yield determining factor, the duration and intensity varying in different cocoa producing areas. It has adverse effects on cocoa, by causing premature leaf fall. However, in India the palms under which cocoa is cultivated, themselves offer some protection to the intercrops, the damage caused is minimal or non-existent (Balasimha, 2002). The dry seasonal Harmattan winds s weeps down from the Sahara into the world's top cocoa grower (Ivory Coasts), generally between December and March. Sometimes it blows for weeks, causing flowers and cherelles to drop off trees in badly hit areas (WCF, 2008).

The pattern in the cocoa belt of India is totally different with the bulk of the rain received in two or three months. It remains rain free for as long as four months in the southern districts of Kerala and as much as six months towards the northern parts of the state and the southern part of Karnataka. Such a rainfall distribution indicates the necessity of providing irrigation in India.

The peak period of flowering in cocoa occurred during May, where the peak period of harvest is in March and October, indicated a lag of 6-7 months between flowering and harvest. The mean annual fruit set was only 3% and out of this only about one fourth reached the maturity. It is found that more than 60% of the yield came from fruit set during January and February. Fruit set was generally more from December to June and very low or absent during July – September. The fruit load of plants also affects flowering intensity, there being a decrease in flowering during intense fruit development period.

The plant needs equitable climate with well distributed rainfall. It requires an annual rainfall of 1500-2000 mm with a minimum of 90-100 mm rainfall per month with a minimum bright sunshine of 4.0 h/day. The optimum temperature range for cocoa varies from 21.1°C to 32.2°C, with a mean monthly minimum of 15°C as the lower limit and an absolute minimum of 10°C and a maximum of 30°C - 32°C.

It is noted that flower initiation has been enhanced during the dry period and only flower growth is inhibited by moisture deficiency. It is reported that a marked decline in flowering near the end of the rainy season when rainfall is very high. Reduced flowering during rainy season is attributed to excessive rainfall with waterlogging and lower temperature. It is observed that fruit set was strongly influenced by rainfall which occurred four to twelve weeks earlier. Flowering was inhibited when the monthly mean temperature was below 23°C. It is observed that as compared to plants growing in the regions with a day temperature of 23.3°C, plants in the region with a day temperature of 26.6°C to 30°C had more active flowering cushions per plant and more number of flowers per cushion per week. It is noted that low temperature during June-August was responsible for the lack of harvest during the period of January to March. A decline of 39% in annual yield was noticed when a sudden rise in maximum temperature of the order of 2-3°C was recorded when compared to that of normal maximum surface air temperature (33.0-36.5°C). In the light of the above facts, the present investigations were undertaken in detail on the aspects of flowering and fruiting behaviour, pod and bean characters of cocoa. Besides, the past yield data of cocoa trees were collected and analysed to understand the yield response of cocoa to various weather variables.

Materials and Methods

3. MATERIALS AND METHODS

The present study on ‘Crop weather relationships of cocoa (*Theobroma cacao* L.)’ was undertaken at the Department of Agricultural Meteorology, College of Horticulture, Vellanikkara from April 2007 to March 2008. The experimental site is located in the farm of Cadbury – KAU Co-operative Cocoa Research Project, Vellanikkara. The station is located at $10^{o}31'$ North latitude and $76^{o}13'$ East longitude at an elevation of 45 m above mean sea level in the central zone of Kerala.

3.1. Experimental Material

The experiment on the ‘Crop weather relationships of cocoa’ was carried out using 30 bearing cocoa trees. The experimental cocoa trees were 20 – years- old. Out of these, 15 were being grown under the shade of rubber and 15 under open conditions. The trees were being irrigated in severe drought months. The plants were categorized based on the mean annual yield. The plants grown in shade were classified as plants giving yield of <15, 15-30 and more than 30 pods per tree per year. In the same way, plants in open were classified as plants giving yield of <60, 60-90 and more than 90 pods per tree per year. In each yield category, five plants were selected and marked for the weekly observation. The selected plants belong to Forastero type of cocoa.

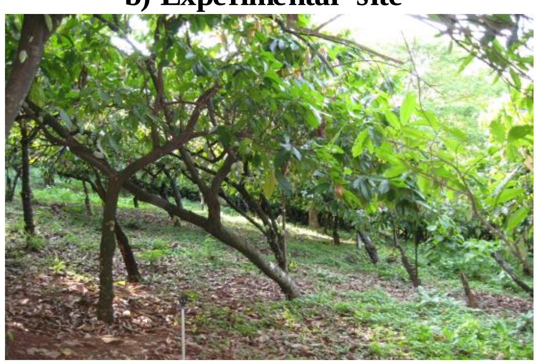
3.1.1. Soil

The soil of the farm is sandy clay loam in texture and Utisol in order. Important physical and chemical properties of the soil in the farm are given below.

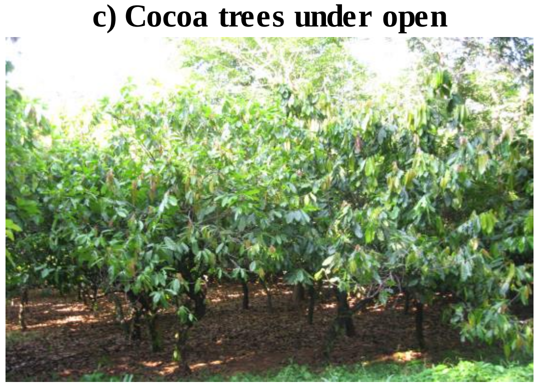
Plate.1. Location of Experimental site

a) Way to experimental site

b) Experimental site

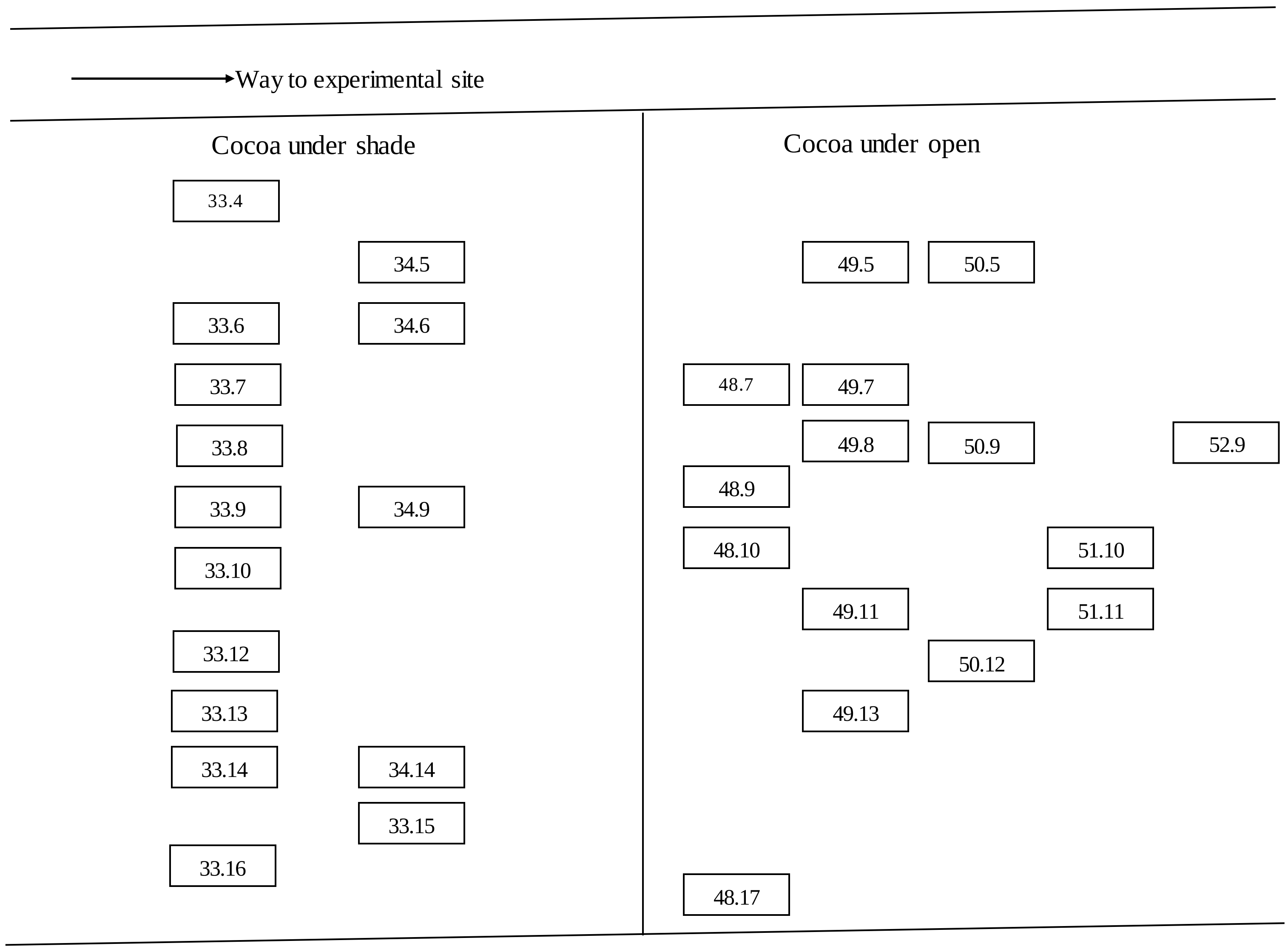


c) Cocoa trees under open



d) Cocoa trees under shade

Lay-out of Experimental site



Physical properties	Value	Method used
A) Mechanical composition		International pipette method (Piper, 1942)
Sand (%)	55.3	
Silt (%)	13.4	
Clay (%)	31.3	
Textural class	Sandy clay loam	
B) Chemical properties		
Organic carbon (%)	0.57	Walkley and Black rapid titration method (Jackson, 1958)
Total Nitrogen (%)	0.04	Microkjeldhal method (Jackson, 1958)
Available phosphorus (kg/ha)	22.5	Ascorbic acid and reduced molybdo phosphoric blue colour method (Watannabure and Olsen, 1965)
Available potassium (kg/ha)	139.6	Flame photometry, Neutral normal ammonoium acetate extraction (Jackson, 1958)

3.1.2. Climate

The experimental location falls under the tropical humid climate of B_4-type as per the Thornthwaite (1948) climatic classification. The area enjoys a warm humid tropical climate with an average annual rainfall of 2800 mm. The area is benefited both by the Southwest and Northeast monsoons, but a maximum share (68-72%) from southwest monsoon. The maximum precipitation (735.5mm) is received during June, followed by July. December to April form the dry months with scattered downpour. February, March and April are the hottest months with a mean maximum temperature of 35.4°C. Unusual and pre-monsoon showers are expected from March to May. Heavy rainfall from June-September, followed by a prolonged dryspell from November is a climatic feature under which cocoa is grown. A strong dry wind is noticed from 15th November to Middle of February due to Palghat gap. It is a special feature in this part of Kerala.

3.1.3. Phenological observations

The biotic events viz., flower and fruiting characters were recorded once in a week from April 2007 to March 2008. Besides, the total pods harvested per tree per month was also recorded. The following observations were taken during the study period.

a. Total number of flowers/tree

Cocoa being an year-round bloomer with flowers all over the tree, a sampling procedure was adopted for taking weekly flower counts. Two metre length of the tree trunk was marked from the base and flowers produced on this area were considered for the study. The old flowers were identified and excluded by the dried appearance of the stigmatic surface, change of the petal colour from creamy white to deep yellow, the drooping character of unpollinated flowers and by swollen ovaries of the fertilized flower as suggested by Purseglove (1974) and Murray (1975).

b. Total number of pod set / tree

The pod set is referred to a newly created small pod from a pollinated flower. The number of pod set was also counted once in a week on the trunk.

c. Total number of cherelle / tree/ year

The cherelle is referred to the elongation of immature pods from the pod set. The number of cherelle was also counted once in a week on the trunk.

c. Total number of pods harvested per tree per month

The total number of pods harvested per tree per month was recorded from the selected plants.

d. Pod and bean characters:

Pod and bean characters like pod weight, wet bean weight and dry weight of a single bean per tree was recorded once in a season. To measure the bean weight, the fruits collected from the trees were broken and beans were manually separated. The separated

Plate.2. Appearance of flowers, pod set and cherelle in cocoa

Appearance of flowers in cocoa

Newly set pod in cocoa tree

Appearance of cherelle in cocoa

Plate.3. Different phases of pod development

a) Flowers

b) Pod set

b) Two weeks after pod set

c) One month after pod set

d) Two months after pod set

e) Three months after pod set

f) Four months after pod set

g) Five months after pod set

h) Six months after pod set

beans were kept in hot air oven at a temperature of 50-60°C for three to four days for getting dry weight of the bean.

3.1.4. Meteorological data

Daily meteorological data on maximum and minimum temperatures, relative humidity (morning and evening), rainfall and rainy days, bright sunshine hours, evaporation and cloud amount were collected from the Department of Agricultural meteorology, College of Horticulture. The weekly mean values of air temperature and relative humidity were worked out from the daily data.

3.1.5. Shade measurement

By using the portable lux meter the light intensity was measured under the canopies of Cocoa, Cocoa + Rubber, Rubber and in open. From the above, the available light in terms of shade was calculated by deducting actual values from the open. The lux metre readings were taken at monthly intervals.

3.2. Statistical Methods

The biotic events collected from plants were pooled in Standard Meteorological-Week wise to get the mean of a particular week of a test cultivar. Correlation and regression analysis were done between the flowering and yield with the weekly rainfall, rainy days, maximum temperature, minimum temperature, bright sunshine, growing degree days and relative humidity.

3.2.1. Total number of flowers/tree

The mean number of flowers per tree per week was calculated from the total flower number. This was pooled into different yield groups. The weather parameters were also averaged weekly and statistical analysis were carried out.

3.2.2. Total number of pod set / tree

The pod set from each tree was pooled into different yield category and the data were subjected to analysis.

3.2.3. Total number of cherelles / tree

The cherelle from each tree was pooled into different yield category and the data were subjected to analysis.

3.2.4. Total number of pods harvested per tree per month

The total number of pods harvested from the experimental trees was recorded and subjected to analysis.

3.2.5. Pod and bean characters

Pod and bean characters like pod weight, wet bean weight and dry weight of a single bean per tree was recorded seasonally. The following are the seasons considered for this study;

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

The observations were recorded during the above period. The weather parameters during the above period also derived from the daily weather data. Then, the data were processed and subjected to agro-climatic analysis through various statistical tools.

3.2.6. Growing degree days (GDD)

The growing degree days (GDD) were worked out during the experimental period to find out the relationship between GDD and biotic events such as flowering, cherelle production, fruit set and pod production. The GDD were calculated using the following formula. The base/threshold temperature is assumed as 10°C for cocoa, below which frost injury takes place.

$$GDD = \frac{T\ maximum + T\ Minimum}{2} - T\ base$$

3.2.7. Helio-thermal unit (HTU)

The helio-thermal unit (HTU) was worked out during the experimental period to find out the relationship between HTU and biotic events of cocoa. The HTU was calculated using the following formula:

HTU = GDD x Actual bright sunshine

3.3. Cocoa yield

The monthly cocoa yield of the Cadbury - KAU Co-operative Cocoa Research Project farm were collected for 100 trees from 1991 to 2007 and analysed. The weather data for the above period was also collected and pooled according to the yield data. The annual cocoa yield over the State of Kerala was also collected for 25 years from 1982-83 to 2007-08. Rainfall and temperature for the above period were also collected and agro-climatic analysis was carried out. The yearly yield data of the farm and the State were analysed using student-t distribution to understand the effect of alternate bearing on cocoa yield.

Results

4. RESULTS

The results obtained on various phenological characters are summarised based on the statistical analysis and presented in this chapter.

4.1. Flowering

The flower production in cocoa was seen throughout the year though weekly variations were significant and almost no flowers were recorded in August. The mean number of flowers varied between 0.1/plant in August (Table.3) and 46.6/plant in May, followed by March (31.9/plant). It was initiated in November (7.8/plant) after the rainy period and thereafter an increasing trend was seen in number of flowers. The flower production significantly increased from January (18.9/plant) and attained a peak in May (46.6/plant),

Table.3 Mean monthly flower production in cocoa at CCRP Farm, Vellanikkara for April, 2007 – March, 2008

Months	Mean (flowers/tree)	% in annual
April ‘07	18.5	10.7
May ‘07	46.6	26.9
June ‘07	6.3	3.7
July ‘07	3.1	1.8
August‘07	0.1	0.1
September‘07	2.0	1.2
October‘07	1.9	1.1
November‘07	7.8	4.5
December‘07	4.6	2.7
January‘08	18.9	10.9
February‘08	31.1	17.9
March‘08	31.9	18.5

which contributed 26.9 per cent to the total annual flower production. The percentage contribution during February and March was 17.9 and 18.5 per cent, respectively. There was a sudden decline in flower production during the rainy months (June, July, August, September and October) and insignificant when compared to other seasons. Prolonged rainy season was noticed during monsoon 2007 and total monsoon rainfall was 3274.5 mm, spread in 93 rainy days. It was the extreme excess rainfall year in recent decades and led to floods in many parts of the State of Kerala. Normally, the monsoon rainfall over the region is 2122.3 mm, spread in 80 rainy days.

4.1.1. Flowering pattern in open and shade

The flowering pattern of cocoa in the open and shade was similar as the commencement of flowering took place in November after the rainy period (June-October). In both the cases, the peak flowering was seen between January and May (Table.4). The percentage contribution of January, February and March in open and shade

Table.4 Flower production in cocoa under open and shade at CCRP Farm, Vellanikkara for April, 2007 – March, 2008

Months	Open		Shade	
	Mean (flowers/tree)	% in annual	Mean (flowers/tree)	% in annual
April ‘07	27.3	11.9	9.7	8.3
May ‘07	73.6	32.2	19.5	16.7
June ‘07	8.9	3.9	3.8	3.3
July ‘07	3.3	1.4	2.9	2.5
August‘07	0.0	0.0	0.3	0.2
September‘07	2.2	1.0	1.9	1.6
October‘07	1.6	0.7	2.1	1.8
November‘07	4.8	2.1	10.9	9.3
December‘07	3.1	1.4	6.1	5.2
January‘08	24.1	10.5	13.7	11.7
February‘08	38.2	16.7	23.9	20.5
March‘08	41.7	18.2	22.1	18.9

was 10.5, 16.7, 18.2 and 11.7, 20.5, 18.9 to the total annual flower production, respectively. However, the number of flowers produced in the open during summer was much higher (68.8 %) when compared to that of the shade (52.3 %). The average number of flowers was always higher (64.6 %) in the open conditions when compared to the cocoa grown under shade conditions (35.4 %). There was an annual difference of 29.2 per cent in number of flowers produced between the open and shade (Table.5). The overall percentage contribution of number of flowers during summer was high (62.2 %) when compared to that of the other seasons. It was only 5.6 per cent in rainy season (June-September) and 9.4 per cent during post monsoon season (October-November) while 22.8

Table.5 Seasonal flower production (flowers/tree) in cocoa during April, 2007 – March, 2008

Seasons	Summer (Feb-May)		SWM (Jun – Sep)		Post monsoon (Oct-Nov)		Winter (Dec-Jan)		Total	
	Mean	%	Mean	%	Mean	%	Mean	%	Mean	%
Open	45.2	68.8	3.6	5.5	3.2	4.9	13.6	20.8	65.6	64.6
Shade	18.8	52.3	2.2	6.1	5.1	14.2	9.9	27.4	36.0	35.4
Mean	32.0	62.2	2.9	5.6	4.9	9.4	11.8	22.8	51.6	50.8

per cent in winter (Dec-Jan). It revealed that the flower production was more (32/plant) during summer in both open (45.2/plant) and shade (18.8/plant) conditions and insignificant in monsoon months. The flowering of cocoa commenced in November after the heavy wetspell during the rainy season and reached to its peak before the monsoon commenced. The monsoon over this region, where cocoa is grown as intercrop, commences on 1st June ± 7 days.

4.1.2. Flowering behaviour in different yield groups

All the yield groups showed similar trend in flowering pattern of cocoa. It was also similar in the open as well as shade. However, the percentage contribution in flower production varied depending upon the yield group though it was high in summer irrespective of the yield group (Table 6). It varied from 37.6 (>30 pods/tree/year) to 81.3 (<60 pods/tree/year). The mean number of flowers produced during rainy season was insignificant (2.9/plant) when compared to that of summer (32.1/plant). It revealed that the flowering behaviour in different yield groups of cocoa also followed uniform pattern. It commences in October / November depending upon the duration of rainy period during the monsoon season. It gradually increases from November and reaches to its peak by the end of May and number of flowers was low during the heavy monsoon season in the humid tropics. Altogether, the percentage flower production during summer was about 60.6 per cent, varying between 37.6 per cent and 81.3 depending upon the yield group in cocoa.

Table.6 Mean number of flowers per plant in open and shade in different yield groups of cocoa

Yield group (pods/tree/year)		Summer (Feb-May)		SWM (Jun - Sep)		Post monsoon (Oct-Nov)		Winter (Dec-Jan)	
		Mean	%	Mean	%	Mean	%	Mean	%
Open	>90	43.2	61.4	4.9	6.9	6.1	8.7	16.2	23.0
	60-90	29.7	60.1	2.3	4.6	1.9	3.9	15.5	31.4
	<60	62.9	81.3	3.7	4.7	1.6	2.1	9.2	11.9
Shade	>30	14.9	37.6	2.8	7.0	7.7	19.5	14.2	35.9
	15-30	23.3	48.2	2.7	5.5	11.4	23.6	11.0	22.8
	<15	18.3	75.3	1.2	4.9	0.4	1.6	4.4	18.1
Mean		32.1	60.6	2.9	5.6	4.9	9.9	11.8	23.9

4.1.3. Multicollinearity effect

The correlation coefficients between different weather variables were performed here to understand the inter-relationship among different weather variables (Table.7). It indicated that the rainfall had significant negative correlation with bright sunshine (-0.786), maximum temperature (-0.702) while positive correlation with morning (0.591)

Table.7 Relationship among weather variables

Weather variables	Max.tem	Min.tem	RH I	RH II	BSS	Rainfall	Rainy days
Rain fall	-0.702**	-0.063	0.591**	0.770**	-0.786**	1.000	0.874**
Rainy days	-0.773**	-0.004	0.690**	0.865**	-0.896**	0.874**	1.000
Max.temp	1.000	0.329*	-0.539**	-0.798**	0.798**	-0.702**	-0.773**
Min.temp	0.329*	1.000	0.141	0.144	-0.055	-0.063	-0.004
RH I	0.539**	0.141	1.000	0.834**	-0.666**	0.591**	0.690**
RH II	-0.798**	0.144	0.834**	1.000	-0.886**	0.770**	0.865**
BSS	0.798**	-0.055	-0.666**	-0.886**	1.000	0.786**	-0.896**

** Correlation significant at 0.01 level; * Correlation significant at 0.05 level

and afternoon relative humidity (0.770), and number of rainy days (0.874). Bright sunshine also had strong negative relationship with rainfall (-0.786), number of rainy days (-0.896), morning (-0.666) and afternoon (-0.886) relative humidity. Due to multicollinearity among different weather variables, a positive correlation with rainfall may result to negative correlation with maximum temperature and bright sunshine and *vice versa*. It was attributed due to dip in maximum temperature and bright sunshine when rainy season commences by June and continues till September. Similarly, the relative humidity is very high with more number of rainy days during the rainy season, resulting in positive correlation with them. The minimum temperature had no significant correlation with weather variables except with maximum temperature. Both maximum temperature and bright sunshine had a strong positive correlation (0.798).

4.1.4. Relationship between weather parameters and flower production

The results of the simple correlation analysis between weather parameters zero to 12 weeks before flower production and number of flowers are presented in Table 8. Out

Table.8 Relationship between weather variables of previous one to 12 weeks and weekly flower production

Weeks prior to	Max.Tem	Min. Tem	RH I	RH II	BSS	Rainy days
0 week	0.527**	0.326*	-0.211	-0.401**	0.536**	-0.434**
1 week	0.435**	0.269	-0.156	-0.325*	0.411**	-0.348**
2 week	0.465**	0.184	-0.232	-0.339*	0.316*	-0.267
3 week	0.571**	0.131	-0.386**	-0.486**	0.418**	-0.414**
4 week	0.592**	0.090	-0.521**	-0.617**	0.500**	-0.526**
5 week	0.572**	0.121	-0.534**	-0.628**	0.502**	-0.560**
6 week	0.516**	0.114	-0.431**	-0.650**	0.525**	-0.517**
7 week	0.493**	0.055	-0.336*	-0.595**	0.438**	-0.475**
8 week	0.421**	-0.085	-0.318*	-0.547**	0.403**	-0.522**
9 week	0.396**	-0.207	-0.380**	-0.559**	0.409**	-0.508**
10 week	0.308*	-0.266	-0.518**	-0.549**	0.416**	-0.470**
11week	0.242	-0.301*	-0.591**	-0.537**	0.464**	-0.451**
12 week	0.176	-0.361**	-0.565**	-0.535**	0.502**	-0.445**

** Correlation significant at 0.01 level; * Correlation significant at 0.05 level

of the seven weather variables, four were negatively and significantly related to flower production in many instances, while two showed positive and significant correlation. The maximum temperature and sunshine hours had significant positive correlation with number of flowers while morning and evening relative humidity, total rainfall and number of rainy days showed negative relationship with the behaviour of flowering in cocoa. The minimum temperature showed both positive and negative relationships during the flowering period in different weeks.

4.1.4.1 Rainfall

Rainfall had an overall significant negative influence on flowering as it is less during the rainy season. When the whole period was considered, the highest correlation coefficient value was -0.448, corresponding to the rainfall of five weeks prior to flowering. In order to find out the probable seasonal differences, correlation study was conducted with flower production and rainfall of summer and rainy period separately as the flower production between summer and rainy season was quite different. The period from June to October and December to May was considered for rainy and summer period, respectively. The relationship between summer rainfall and flower production indicated that the influence was positive during second week before flowering with a correlation co-efficient of 0.763 (Table.9) while monsoon rainfall showed a negative relationship with flower production as it had a correlation coefficient of -0.464 during the sixth week before flowering.

Table.9 Relationship between rainfall and flower production

Week No.	Summer rainfall (Dec - May)	Monsoon rainfall (Jun-Oct)	Total period
0 week	-0.014	-0.035	-0.391**
1 week	0.221	-0.211	-0.368**
2 week	0.763**	-0.337	-0.296*
3 week	0.492*	-0.350	-0.354**
4 week	-0.151	-0.402	-0.438**
5 week	-0.392*	-0.337	-0.448**
6 week	-0.356*	-0.464*	-0.446**
7 week	-0.384*	-0.428*	-0.428**
8 week	-0.504**	-0.349	-0.424**
9 week	-0.525**	-0.387	-0.427**
10 week	-0.509**	-0.258	-0.401**
11week	-0.532**	-0.327	-0.404**
12 week	-0.541**	-0.222	-0.387**

** Correlation significant at 0.01 level; * Correlation significant at 0.05 level

4.1.4.2 Number of Rainy days

The influence of rainy days was also negative with the highest value of -0.560 for the fifth week prior to flowering. It is obvious that the number of rainy days and heavy rainfall had negative correlation with the flower behaviour in cocoa as the flower production is very low and insignificant during the rainy season.

4.1.4.3 Maximum temperature

The maximum temperature always had a positive relationship with flower production from the first to tenth week before flowering. The highest correlation value of 0.592 was noted during the fourth week before flowering, followed by the fifth week (0.572). Such a relationship is expected as number of flowers produced is more during summer in which the maximum temperature is high. Normally, the maximum temperature varies between 32.8 to 36.1^{o}C from January to May.

4.1.4.4 Minimum temperature

The minimum temperature recorded both positive and negative relationship with the flower production. The highest value (-0.361) was noted during 12 weeks before flowering. No significant correlation was found between the two variables throughout the flowering period except 1st, 11th and 12th week before flowering. The minimum temperature had no correlation with any other weather variable except with maximum temperature.

4.1.4.5 Relative humidity

Both morning and evening relative humidity showed negative influence on flower production. A value of -0.591 was recorded for morning relative humidity during 11th week. The relationship between afternoon relative humidity and flowering was significant during 4-6th week before flowering as it had maximum (-0.617 to -0.650) correlation co-efficient. Negative correlation is expected with relative humidity as it depends on maximum temperature. If maximum temperature is more, the relative humidity is less. It is the reason why, a positive significant correlation with maximum temperature results in negative correlation with relative humidity.

4.1.4.6 Bright sunshine

The duration of bright sunshine hours had a positive effect on flowering with maximum (0.536) effect during the week of flowering itself. The second maximum was (0.500 - 0.525) recorded during 4-6th week before flowering. It appears that the flowering in cocoa needs better sunshine.

It revealed that the cumulative effect of weather variables from 0-12 weeks influenced the flowering either positively or negatively depending upon the weather variables. Rainfall, number of rainy days and relative humidity influenced the flowering negatively while maximum temperature and bright sunshine positively.

4.2. Pod set

The pod set in cocoa was seen throughout the year though weekly variations were significant and almost no pod set was recorded in August. The mean number of pod set varied between 0.1/plant in October (Table.10) and 6.2/plant in February, followed by

Table.10 Mean monthly number of pod set in cocoa at CCRP Farm, Vellanikkara for April, 2007 – March, 2008

Months	Mean (pod set/tree)	% in annual
April ‘07	2.7	9.9
May ‘07	3.2	11.8
June ‘07	1.9	7.1
July ‘07	0.5	2.0
August‘07	0.1	0.4
September‘07	0.2	0.6
October‘07	0.2	0.9
November‘07	1.0	3.6
December‘07	1.7	6.2
January‘08	3.2	12.0
February‘08	6.2	23.2
March‘08	6.0	22.3

March (6.0/plant). It was initiated in November (1.0/plant) after the rainy period and thereafter an increasing trend was seen in number of pod set. The pod set significantly increased from January (3.2/plant) and attained a peak in February (6.2/plant) which contributed 23.2 per cent to the total annual number of pod set. The percentage contribution of March was 22.3 per cent. There was a sudden decline in pod set during the rainy months (June, July, August, September and October) and insignificant when compared to other seasons.

4.2.1. Pod set in open and shade

The pod set pattern of cocoa in the open and shade was similar as the commencement of pod set took place in November after the rainy period (June-October). In both the cases, the peak pod set was seen between January and May (Table.11).

Table.11 Pod set in cocoa under open and shade at CCRP Farm, Vellanikkara for April, 2007 – March, 2008

Months	Open		Shade	
	Pod set/tree	% in annual	Pod set/tree	% in annual
April ‘07	3.1	9.0	2.3	11.5
May ‘07	4.0	11.7	2.3	11.8
June ‘07	2.5	7.4	1.3	6.5
July ‘07	0.4	1.2	0.7	3.4
August‘07	0.1	0.2	0.1	0.7
September‘07	0.3	0.8	0.1	0.3
October‘07	0.1	0.4	0.3	1.7
November‘07	0.7	2.0	1.3	6.5
December‘07	1.1	3.4	2.2	11.3
January‘08	4.0	11.7	2.5	12.5
February‘08	8.6	25.2	3.9	19.6
March‘08	9.2	27.0	2.8	14.2

However, the number of pod set in the open during summer was much higher (62.1 %) when compared to that of the shade (44.1 %). The percentage contribution of January, February and March in open and shade was 11.7, 25.2, 27.0 and 12.5, 19.6, 14.2 to the total annual number of pod set, respectively. The average number of pod set was always higher (61.0 %) in the open conditions when compared to the cocoa grown under shade conditions (39.0 %). There was an annual difference of 22.0 per cent in number of pod set between the open and shade (Table 12). The overall percentage contribution of number of pod set during summer was high (54.8 %) when compared to that of the other seasons. It

Table.12 Seasonal number of pod set (pod set/tree) in cocoa during April, 2007 – March, 2008

Seasons	Summer (Feb-May)		South West Monsoon (Jun - Sep)		Post monsoon (Oct-Nov)		Winter (Dec-Jan)		Average	
	Mean	%	Mean	%	Mean	%	Mean	%	Mean	%
Open	6.2	62.1	0.8	8.2	0.4	4.0	2.6	25.7	10.0	61.0
Shade	2.8	44.1	0.5	8.3	0.7	11.1	2.3	36.5	6.3	39.0
Mean	4.5	54.8	0.7	8.2	0.6	7.3	2.5	29.7	8.3	50.9

was only 8.2 per cent in rainy season (June-September) and 7.3 per cent during post monsoon season (October-November) while 29.7 per cent in winter (Dec-Jan). It revealed that the number of pod set was more (4.5/plant) during summer (February-May) in both open (6.2/plant) and shade (2.8/plant) conditions and insignificant in monsoon months (June-September). The pod set of cocoa commenced in November after the heavy wetspell during the rainy season and reached to its peak before the monsoon commenced.

4. 2.2. Pod set in different yield groups

All the yield groups showed similar trend in pod set of cocoa. It was also similar in the open as well as shade. However, the percentage contribution in pod set varied depending upon the yield group though it was high in summer irrespective of the yield group (Table 13). It varied from 28.7 (15-30 pods/tree/year) to 73.4 (<60 pods/tree/year).

Table.13 Mean number of pod set per plant in open and shade in different yield groups of cocoa

Yield group (pods/tree/year)		Summer (Feb-May)		SWM (Jun - Sep)		Post monsoon (Oct-Nov)		Winter (Dec-Jan)	
		Mean	%	Mean	%	Mean	%	Mean	%
Open	<90	5.4	50.9	0.9	8.5	0.9	8.5	3.4	32.1
	60-90	5.8	62.7	0.5	4.9	0.2	2.2	2.8	30.2
	<60	7.5	73.4	1.1	10.8	0.1	1.0	1.5	14.8
Shade	>30	2.7	37.5	0.6	8.3	1.1	15.3	2.8	38.9
	15-30	2.1	28.7	0.6	8.4	1.1	15.4	3.4	47.5
	<15	3.7	72.5	0.4	7.9	0.2	3.9	0.8	15.7
Mean		4.5	54.3	0.7	8.1	0.6	7.7	2.5	29.9

The mean number of pod set during rainy season was insignificant (0.7/plant) when compared to that of summer (4.5/plant). It revealed that the pod set in different yield groups of cocoa also followed uniform pattern. It commences in October / November depending upon the duration of rainy period during the monsoon season. It gradually increases from November and reaches to its peak by the end of May and number of pod set was minimum during the heavy monsoon season in the humid tropics. Altogether, the percentage pod set during summer was about 54.8 per cent, varying between 28.7 and 73.4 per cent depending upon the yield group in cocoa.

4.2.3 Relationship between weather parameters and pod set

4.2.3.1 Rainfall

Rainfall had an overall significant negative influence on pod set. The highest correlation coefficient was -0.447, corresponding to the rainfall of five weeks prior to pod set.

4.2.3.2 Number of Rainy days

The influence of rainy days was also negative with the highest value of -0.538 for the sixth week prior to pod set (Table.14). It is obvious that the number of rainy days and heavy rainfall had negative correlation with the pod set in cocoa as the pod set is very low and insignificant during the rainy season.

Table.14 Relationship between weather variables of previous one to 12 weeks and weekly pod set

Weeks prior to	Max.Temp	Min. Temp	RH I	RH II	BSS	Rainfall	Rainy days
0 week	0.560**	0.041	-0.429**	-0.557**	0.538**	-0.339*	-0.434**
1 week	0.511**	0.034	-0.376**	-0.554**	0.563**	-0.450**	-0.518**
2 week	0.357**	0.032	-0.369**	-0.450**	0.385**	-0.364**	-0.355**
3 week	0.432**	-0.024	-0.419**	-0.516**	0.459**	-0.362**	-0.406**
4 week	0.423**	-0.124	-0.433**	-0.582**	0.493**	-0.422**	-0.464**
5 week	0.415**	-0.220	-0.536**	-0.618**	0.499**	-0.447**	-0.525**
6 week	0.397**	-0.124	-0.655**	-0.616**	0.494**	-0.444**	-0.538**
7 week	0.342*	-0.134	-0.514**	-0.569**	0.467**	-0.432**	-0.469**
8 week	0.284*	-0.202	-0.574**	-0.564**	0.443**	-0.438**	-0.526**
9 week	0.212	-0.255	-0.412**	-0.460**	0.411**	-0.407**	-0.482**
10 week	0.230	-0.363**	-0.462**	-0.484**	0.372**	-0.403**	-0.464**
11week	0.157	-0.375**	-0.552**	-0.466**	0.339*	-0.373**	-0.429**
12 week	0.073	-0.204	-0.524**	-0.356**	0.299*	-0.368**	-0.386**

** Correlation significant at 0.01 level (2-tailed); * Correlation significant at 0.05 level (2-tailed)

4.2.3.3 Maximum temperature

The maximum temperature always had a positive relationship with pod set from the first to seventh week before pod set. The highest correlation value of 0.560 was noted during the week itself, followed by the first week (0.511). Such a relationship is expected as number of pod set is more during summer in which the maximum temperature is high.

4.2.3.4 Minimum temperature

The minimum temperature recorded both positive and negative relationship with the pod set. The highest value (-0.375) was noted during 11th week before pod set. No significant correlation was found between the two variables throughout the pod set period except 10th and 11th week before pod set.

4.2.3.5 Relative humidity

Both morning and evening relative humidity showed negative influence on pod set. A value of -0.655 was recorded for morning relative humidity during sixth week. The relationship between afternoon relative humidity and pod set was significant during 4-6th week before pod set as it had maximum (-0.582 to -0.616) correlation co-efficient.

4.2.3.6 Bright sunshine

The duration of bright sunshine hours had a positive effect on pod set with maximum (0.560) effect during the week of pod set itself. The second maximum (0.500 - 0.525) recorded during 4-6th week before pod set. It appears that the pod set in cocoa needs better sunshine.

It revealed that the cumulative effect of weather variables from 0-12 weeks influenced the pod set either positively or negatively depending upon the weather variables. Rainfall, number of rainy days and relative humidity influenced the pod set negatively while maximum temperature and bright sunshine positively. The relationship between various weather variables and pod set of cocoa exactly followed the same trend as in the case influence of weather on cocoa flower production. It could be attributed to the dependency of pod set on the number of flowers produced.

4.3. Cherelle

The cherelle production in cocoa was seen throughout the year though weekly variations were significant and no cherelles were recorded in August. The mean number of cherelles varied between nil in August (Table 15) and 4.1/plant in March, followed by

February (3.3/plant). It was initiated in November (0.4/plant) after the rainy period and thereafter an increasing trend was seen in number of cherelles. The cherelle production significantly increased from January (1.4/plant) and attained a peak in March (4.1/plant) which contributed 27.5 per cent to the total annual cherelle production. The percentage contribution of February was 22.4. There was a sudden decline in cherelle production during the rainy months (June, July, August, September and October) and insignificant when compared to other seasons.

Table.15 Mean monthly cherelle production in cocoa at CCRP Farm, Vellanikkara for April, 2007 – March, 2008

Months	Mean (cherelles/tree)	% in annual
April ‘07	1.8	12.3
May ‘07	1.4	9.4
June ‘07	1.3	8.7
July ‘07	0.1	0.2
August‘07	0.0	0.0
September‘07	0.1	0.7
October‘07	0.1	0.2
November‘07	0.4	2.7
December‘07	0.9	6.3
January‘08	1.4	9.6
February‘08	3.3	22.4
March‘08	4.1	27.5

4.3.1. Cherelle production in open and shade

The cherelle production pattern of cocoa in the open and shade was similar as the commencement of cherelle production took place in November after the rainy period (June-October). In both the cases, the peak cherelle production was seen between February and March. The percentage contribution of February and March in open and shade was 23.0, 31.1 and 21.4, 22.0 to the total annual cherelle production, respectively (Table.16). However, the number of cherelles produced in the open during summer was much higher (67.9 %) when compared to that of the shade (49.2 %). The average number of cherelles was always higher (59.1 %) in the open conditions when compared to the cocoa grown under shade conditions (40.9 %). There was an annual difference of 16.8 per cent in number of cherelles produced between the open and shade. The overall percentage contribution of number of cherelles during summer was high (60.2 %) when compared to

Table.16 Cherelle production in cocoa under open and shade at CCRP Farm, Vellanikkara for April, 2007 – March, 2008

Months	Open		Shade	
	Cherelles/tree	% in annual	Cherelles/tree	% in annual
April '07	1.9	10.4	1.8	15.3
May '07	2.4	13.3	0.4	3.4
June '07	1.2	6.7	1.4	11.8
July '07	0.1	0.4	0.0	0.0
August'07	0.0	0.0	0.0	0.0
September'07	0.2	0.7	0.1	0.6
October'07	0.0	0.0	0.1	0.6
November'07	0.3	1.5	0.5	4.5
December'07	0.7	3.7	1.2	10.2
January'08	1.7	9.3	1.2	10.2
February'08	4.1	23.0	2.5	21.4
March'08	5.6	31.1	2.6	22.0

that of the other seasons. It was only 8.2 per cent in rainy season (June-September) and 4.9 per cent during post monsoon season (October-November) while 26.7 per cent (Table 17) in winter (Dec-Jan). It revealed that the cherelle production was more (2.7/plant) during summer (February-May) in both open (3.5/plant) and shade (1.8/plant) conditions and insignificant in monsoon months (June-September). The cherelle production of cocoa commenced in November after the heavy wetspell during the rainy season and reached to its peak before the monsoon commenced.

Table.17 Seasonal cherelle production (cherelles/plant) in cocoa during April, 2007 – March, 2008

Seasons	Summer (Feb-May)		SWM (Jun - Sep)		Post monsoon (Oct-Nov)		Winter (Dec-Jan)		Average	
	Mean	%	Mean	%	Mean	%	Mean	%	Mean	%
Open	3.5	67.9	0.4	6.8	0.1	2.6	1.2	22.7	5.2	58.4
Shade	1.8	49.2	0.4	9.9	0.3	8.7	1.2	32.2	3.7	41.6
Mean	2.7	60.2	0.4	8.2	0.2	4.9	1.2	26.7	4.5	50.5

4.3.2 Cherlle production in different yield groups

All the yield groups showed similar trend in cherlle production of cocoa. It was also similar in the open as well as shade. However, the percentage contribution in cherlle production varied depending upon the yield group though it was high in summer irrespective of the yield group (Table 18). It varied from 33.3 (15-30 pods/tree/year) to 79.7 (<15 pods/tree/year). The mean number of cherelles during rainy season was insignificant (0.4/plant) when compared to that of summer (2.7/plant). It revealed that the

Table.18 Mean number of cherelles per plant in open and shade in different yield groups of cocoa

Yield group (pods/tree/year)		Summer (Feb-May)		SWM (Jun - Sep)		Post monsoon (Oct-Nov)		Winter (Dec-Jan)	
		Mean	%	Mean	%	Mean	%	Mean	%
Open	>90	3.2	60.6	0.3	4.8	0.3	5.8	1.5	28.8
	60-90	3.1	65.3	0.3	5.3	0.1	2.1	1.3	27.3
	< 60	4.3	77.3	0.6	10.0	0.0	0.0	0.7	12.7
Shade	>30	1.5	42.3	0.5	12.7	0.3	8.4	1.3	36.6
	15-30	1.5	33.3	0.3	6.9	0.5	11.5	2.1	48.3
	<15	2.6	79.7	0.4	10.9	0.1	3.1	0.2	6.3
Mean		2.7	59.8	0.4	8.4	0.2	5.2	1.2	26.7

cherlle production in different yield groups of cocoa follows uniform behaviour. It commences in October / November depending upon the duration of rainy period during the monsoon season. It gradually increases from November and reaches to its peak by the end of May and number of cherelles was low during the heavy monsoon season in the humid tropics. Altogether, the percentage cherlle production during summer was about 60.2 per cent, varying between 33.3 % and 79.7 % depending upon the yield group in cocoa.

4.3.3. Relationship between weather variables and cherlle production

4.3.3.1 Rainfall

Rainfall had an overall significant negative influence on cherlle production. The highest correlation coefficient was -0.516, corresponding to the rainfall of two weeks prior to cherlle production.

4.3.3.2 Number of Rainy days

The influence of rainy days was also negative with the highest value of -0.586 for the second week prior to cherlle production. It is obvious that the number of rainy days and heavy rainfall had negative correlation with the cherlle production in cocoa as the cherlle production is very low and insignificant during the rainy season.

4.3.3.3 Maximum temperature

The maximum temperature always had a positive relationship with pod set from the first to ninth week before cherlle production. The highest correlation value of 0.672 was noted during the first week before cherlle production, followed by the second week (0.592). Such a relationship is expected as the number of cherelles produced is more during summer in which the maximum temperature is high.

4.3.3.4 Minimum temperature

The minimum temperature recorded both positive and negative relationship with the cherlle production. The highest value (-0.448) was noted during 11th week before cherlle production (Table.19). No significant correlation was found between the two variables throughout the cherlle production period except 10th to 12th week before cherlle production.

Table.19 Relationship between weather variables of previous one to 12 weeks and weekly cherlle production

Weeks prior to	Max.Temp	Min. Temp	RH I	RH II	BSS	Rainfall	Rainy days
0 week	0.564**	0.102	-0.473**	-0.537**	0.439**	-0.353**	-0.400**
1 week	0.672**	0.050	-0.567**	-0.677**	0.616**	-0.461**	-0.545**
2 week	0.592**	0.002	-0.523**	-0.678**	0.644**	-0.516**	-0.586**
3 week	0.501**	-0.030	-0.458**	-0.650**	0.605**	-0.509**	-0.556**
4 week	0.460**	-0.031	-0.397**	-0.599**	0.544**	-0.477**	-0.509**
5 week	0.433**	-0.139	-0.371**	-0.582**	0.493**	-0.469**	-0.527**
6 week	0.425**	-0.242	-0.533**	-0.645**	0.498**	-0.488**	-0.573**
7 week	0.363**	-0.145	-0.664**	-0.615**	0.449**	-0.482**	-0.581**
8 week	0.339*	-0.223	-0.653**	-0.628**	0.483**	-0.474**	-0.575**
9 week	0.277*	-0.285*	-0.650**	-0.631**	0.523**	-0.463**	-0.557**
10 week	0.207	-0.317*	-0.507**	-0.532**	0.458**	-0.426**	-0.508**
11week	0.203	-0.448**	-0.530**	-0.509**	0.377**	-0.410**	-0.470**
12 week	0.108	-0.429**	-0.515**	-0.416**	0.290*	-0.365**	-0.410**

** Correlation significant at 0.01 level; * Correlation significant at 0.05 level

4.3.3.5 Relative humidity

Both morning and evening relative humidity showed negative influence on cherlle production. A value of -0.664 was recorded for morning relative humidity during seventh week. The relationship between afternoon relative humidity and cherlle production was significant during 4-6th week before cherlle production as it had maximum (-0.599 to -0.645) correlation co-efficient.

4.3.3.6 Bright sunshine

The duration of bright sunshine hours had a positive effect on cherlle production with maximum (0.644) effect during second week before cherlle production. The second maximum (0.616) recorded during one week before cherlle production. It appears that the cherlle production in cocoa needs better sunshine.

It revealed that the cumulative effect of weather variables from 0-12 weeks influenced the cherlle production either positively or negatively depending upon the weather variables. Rainfall, number of rainy days and relative humidity influenced the cherlle production negatively while maximum temperature and bright sunshine positively. The relationship between various weather variables and cherlle production of cocoa exactly followed the same trend as in the case influence of weather on cocoa flower production. It could be attributed to the dependency of cherlle production on the number of flowers set.

4.4. Pods

The number of pods harvested in cocoa was seen throughout the year though monthly variations were significant unlike in perennial crops exhibiting seasonality in harvest (Table 20). The mean number of pods was low in August (0.1 pods/plant) and high in April (5.7 pods/plant), followed by November (5.3 pods/plant).

Table.20 Mean monthly number of pods harvested in cocoa at CCRP Farm, Vellanikkara for April, 2007 – March, 2008

Months	Mean (pods/tree)	% in annual
April '07	5.7	21.6
May '07	0.6	2.1
June '07	1.3	4.7
July '07	0.4	1.5
August'07	0.1	0.3
September'07	0.7	2.8
October'07	3.2	12
November'07	5.3	19.8
December'07	1.1	4.1
January'08	0.6	2.3
February'08	3.7	13.8
March'08	4	15

4.4.1. Number of pods harvested in open and shade

Unlike the flowering, pod set and cherelle production pattern, two peaks were noticed in the number of pods harvested in cocoa (Table.21). The first peak mean harvest was during October (3.2 pods/plant) and November (5.3 pods/plant), followed by summer (February-3.7 pods/plant; March-4 pods/plant and 5.7 pods/plant in April). The yield pattern in cocoa was also dissimilar between the shade and open conditions. In open, the number of pods was more (6.4 pods/plant) during the post monsoon season, followed by summer (3.4 pods/plant). In shade, number of pods harvested was high (3.6 pods/plant) during summer, followed by post monsoon season (2.1 pods/plant). The percentage contribution of pod yield to the annual in October and November under open was 16.6 and 20.9 %, respectively. The contribution of February and March in shade was 22.8 and 28.1 per cent to the total annual number of pods, respectively. It clearly indicated that the influence of weather or other environmental factors appears to be different between open and shade conditions on pod yield as the pattern of yield and the number of pods harvested was not similar.

Table.21 Number of pods harvested (pods/tree) in cocoa under open and shade at CCRP Farm, Vellanikkara for April, 2007 – March, 2008

Months	Open		Shade	
	Pods/tree	% in annual	Pods/tree	% in annual
April '07	7.8	22.9	3.7	19.2
May '07	0	0	1.1	6
June '07	2.5	7.2	0.1	0.4
July '07	0.8	2.3	0	0
August'07	0	0	0.1	0.7
September'07	1.5	4.3	0	0
October'07	5.7	16.6	0.7	3.9
November'07	7.1	20.9	3.4	17.8
December'07	2.1	6.1	0.1	0.7
January'08	1.1	3.3	0.06	0.4
February'08	3	8.8	4.3	22.8
March'08	2.6	7.6	5.3	28.1

The average number of pods was always high (68.1 %) in the open conditions when compared to the cocoa grown under shade conditions (31.9 %). There was an annual difference of 36.2 per cent in number of pods harvested between the open and shade. The overall percentage contribution of number of pods harvested during post monsoon season (Oct-Nov) was high (46.1 %) when compared to that of the other seasons (Table.22). It was only 6.7 per cent in rainy season (June-Sep) and 9.2 per cent during winter season (Dec-Jan) while 38.0 per cent in summer (Feb-May). It revealed that the number of pods harvested was more (6.4 pods/plant) during the post monsoon season followed by summer (3.4 pods/plant) in open while more (3.6 pods/plant) in summer, followed by post monsoon season (2.1 pods/plant) under shade conditions. The pod yield was insignificant (0.6 pods/plant) in monsoon months (June-September) in both the situations when compared to other seasons. The pod yield was very high under open conditions when compared to the shade where the light availability was only 45 per cent.

Table.22 Seasonal number of pods harvested in cocoa during April, 2007 – March, 2008

Seasons	Summer (Feb-May)		SWM (Jun - Sep)		Post monsoon (Oct-Nov)		Winter (Dec-Jan)		Average	
	Mean	%	Mean	%	Mean	%	Mean	%	Total	%
Open	3.4	26.8	1.2	9.5	6.4	51.2	1.6	12.8	12.6	68.1
Shade	3.6	62.4	0.1	0.9	2.1	35.6	0.1	1.7	5.9	31.9
Mean	3.5	38.0	0.6	6.7	4.2	46.1	0.9	9.2	9.2	50.0

4.4.2 Pod production in different yield groups

All the yield groups showed similar trend in number of pods harvested in cocoa under open conditions. It was true in the case of different yield groups under the shade also. However, the percentage contribution in number of pods varied depending upon the yield group though it was high in post monsoon season irrespective of the yield group except in the yield group of >90 pods/plant/year where it was more in summer (Table 23). The mean number of pods during rainy season was insignificant (0.6/plant) when compared to that of post monsoon (4.2/plant) and summer (3.5 pods/plant) seasons in both open and shade conditions. It revealed that the number of pods in different yield groups of cocoa also followed uniform pattern and distinctly different between open and shade. Altogether, the percentage number of pods during post monsoon season was 51.8 per cent in open, varying between 17.7 and 66.4 % depending upon the yield group in cocoa while 59 per cent in summer varying between 0 and 70.2 per cent under shade conditions.

Table.23 Mean number of pods / plant in open and shade in different yield groups of cocoa

Yield group (pods/tree/year)		Summer (Feb-May)		South west monsoon (Jun - Sep)		Post monsoon (Oct-Nov)		Winter (Dec-Jan)	
		Mean	%	Mean	%	Mean	%	Mean	%
Open	>90	5.3	38.5	1.2	8.4	4.3	31.3	3.0	21.8
	60-90	2.9	21.8	1.3	9.5	8.7	66.4	0.3	2.3
	<60	1.9	17.7	1.2	10.7	6.2	57.7	1.5	13.9
	Mean	3.4	26.0	1.2	9.5	6.4	51.8	1.6	12.7
Shade	>30	4.3	54.4	0.0	0.0	3.4	43.0	0.2	2.6
	15-30	6	70.2	0.05	0.6	2.4	28.1	0.1	1.1
	<15	0.6	52.4	0.1	9.5	0.4	38.1	0.0	0.0
	Mean	3.6	59.0	0.05	3.4	2.1	36.4	0.1	1.2
Mean		3.5	42.5	0.6	6.5	4.2	44.0	0.9	7.0

4.4.3. Relationship between weather variables and pod production

The results of the simple correlation analysis between weather parameters zero to 6 months before pod production and number of pods are presented in Table 24. Out of the seven weather variables, only maximum temperature had significant relationship with pod production during the same month. All other weather variables (Minimum temperature, morning and afternoon relative humidity, bright sunshine, rainfall and rainy days) had no significant correlation with the pod production. However, this relationship cannot be taken into account through this type of correlation as the number of values was limited to one year (12 values) only.

Table.24 Relationship between weather variables of previous one to 6 months and monthly pod production

Months	Max.Temp	Min. Temp	RH I	RH II	BSS	Rainfall	Rainy days
0 months	0.662*	0.130	-0.370	-0.471	0.512	-0.523	-0.506
1 months	0.392	-0.080	-0.068	-0.433	0.350	-0.355	-0.349
2 months	-0.061	-0.456	-0.367	-0.293	0.189	-0.171	-0.182
3 months	-0.339	-0.570	-0.388	-0.082	-0.039	-0.054	-0.082
4 months	-0.509	-0.304	-0.093	-0.240	-0.287	0.285	0.219
5 months	-0.371	-0.020	-0.362	-0.496	-0.349	0.294	0.374
6 months	-0.170	-0.275	-0.431	-0.464	-0.292	0.136	0.265

** Correlation significant at 0.01 level; * Correlation significant at 0.05 level

4.5. Pod and bean characters

Pod and bean characters like pod length, width, weight, wet bean weight, dry bean weight and weight of a single dry bean are given in the Table.25. The pods harvested during November (post monsoon season) was superior in pod weight (562 g/pod), pod length (17.03 cm/pod) and dry bean weight (1.28 g/bean). In contrast, the pods harvested during March (summer) were inferior in pod weight (320 g/pod), pod length (13.0 cm/pod) and dry bean weight (0.91g/bean). The pods harvested during September (rainy season) and January (winter) showed intermediary, having the pod weight of 555 g/pod in September and 524 g/pod in January. The pods harvested during summer showed reduction in pod weight and dry bean weight by recorded 44 and 29 per cent, respectively when compared to post monsoon season. As a whole, the number of pods and pod weight were more during the post monsoon season. Though the pod weight was more in rainy season, the number of pods produced were less. In the case of summer, more number of pods were produced with less pod weight. Hence, a harvest of five pods during the post monsoon seasons equals to nine pods harvested during summer season, 5.4 pods during winter while 5.1 pods in south west monsoon.

Table.25 Pod and bean characters over different months/seasons

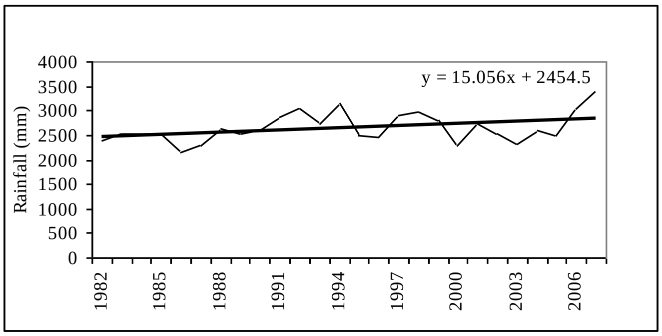
Seasons/months	Length (cm/pod)	Width (cm)	Pod weight	Wet bean weight (g) (20 beans)	Dry bean weight (g) (20 beans)	Single dry bean weight (g)
SWM (Jun-Sep)	16.66	8.34	554.96	44.96	25.04	1.25
Post monsoon (Oct-Nov)	17.03	8.58	561.9	46.13	25.5	1.28
Winter (Dec-Jan)	15.53	8.28	524.34	42.45	22.68	1.13
Summer (Feb-May)	13.24	7.16	319.76	33.14	18.28	0.91

4.6. Climate and cocoa over Kerala

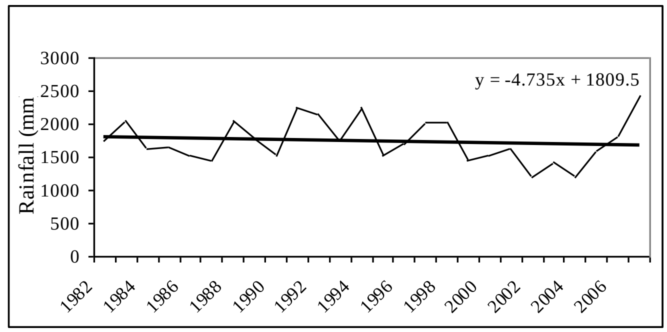
There was an increase (15mm/year) in annual rainfall over Kerala during the study period from 1982-2007 (Fig.2). Such trend did not exist over the long period of data (1871-2007). The annual rainfall was the highest (3421 mm) in 2007 while the lowest (2296 mm) in 2000 over the State of Kerala. The increasing trend in annual rainfall in recent decades could be attributed to heavy rainfall received in 2007. A cyclic trend in seasonal rainfall was also noticed as the monsoon rainfall was declining (4.7mm/year) while increasing (10.2mm/year) in post monsoon rainfall (Fig.3). Similarly, winter rainfall was declining (1.0mm/year) while increasing in summer rainfall (10.1mm/year). Unlike in annual rainfall the seasonal trends in rainfall were similar to that of the long period trend (1871-2007). As the annual rainfall is dependant on monsoon rainfall, the decline in monsoon rainfall over Kerala is the concern. About 68-72 per cent of the annual rainfall is received during the monsoon (June-September) depending upon the location. Hence, the decline in monsoon rainfall is likely to affect several sectors like generation of hydro-power, irrigation during the rabi season and drinking water during summer. Nevertheless, increase in summer and post monsoon rainfall is likely to influence favourably most of the plantation crops. Being the plantation state, it is a

Fig.2. Trend in Rainfall and mean air temperature over Kerala from 1982-2007

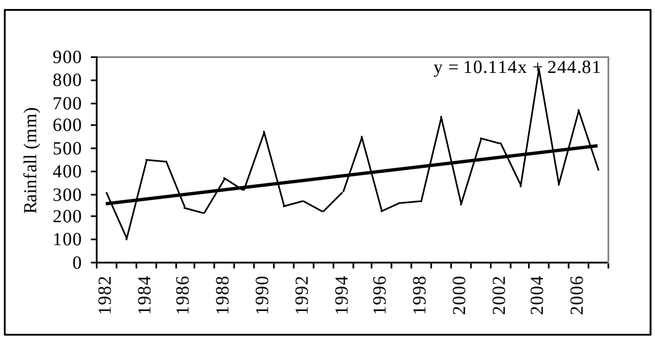
Trend in annual rainfall over Kerala from 1982-2007



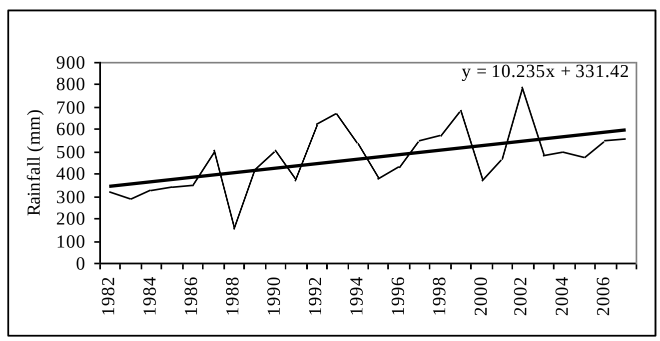
Trend in SWM rainfall over Kerala from 1982-2007



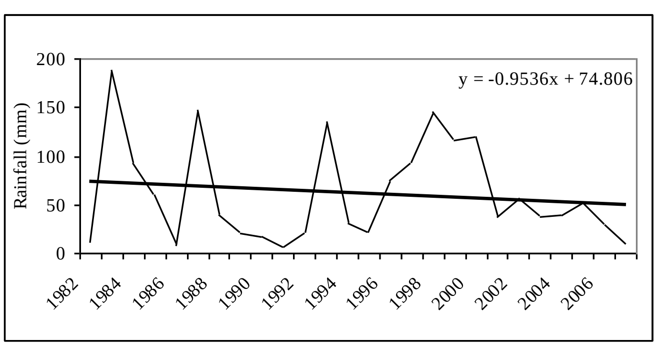
Trend in summer rainfall over Kerala from 1982-2007



Trend in post monsoon rainfall over Kerala from 1982-2007



Trend in winter rainfall over Kerala from 1982-2007



Trend in mean temperature over Kerala from 1982-2003

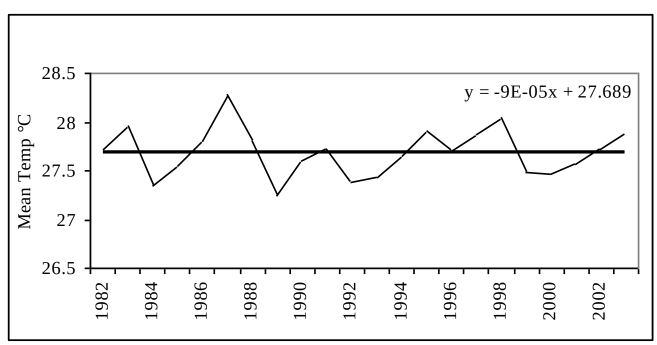
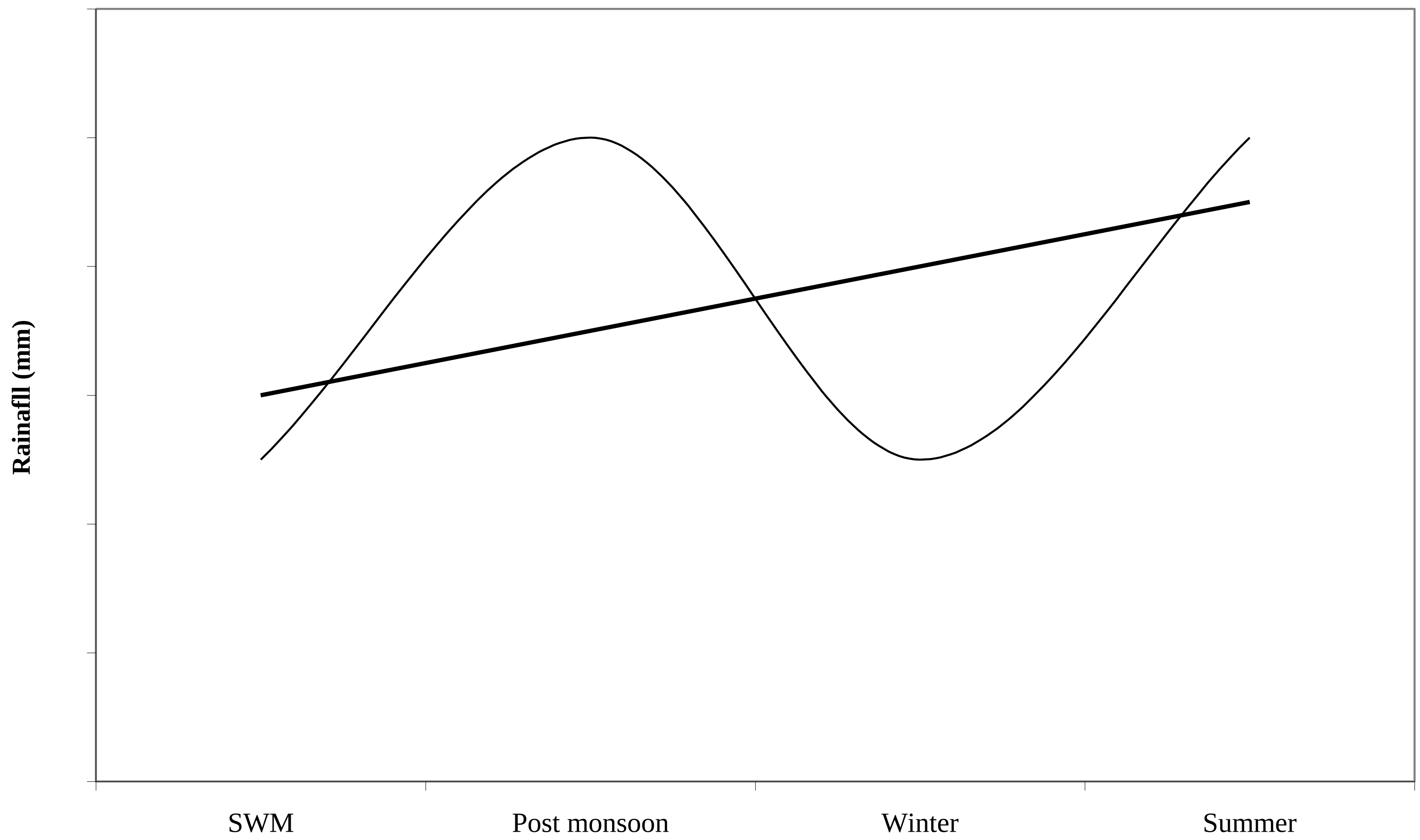


Figure.3 Cyclic trend in rainfall over the State of Kerala



positive sign for sustenance of plantation crops, in terms of soil moisture availability under changed climate scenario.

The State of Kerala is one of the cocoa plantation states and ranked first in India. In 1980s the area under cocoa was very high and revolved around 18,000 ha. Thereafter, a sharp decline was noticed and reached to its low (6900ha) in 1994-95. The percentage decline in area was 62 per cent. A gradual regain in cocoa area was noticed since 1995-96 onwards and stabilized at 10,500ha in 2007-08. Overall there was sharp decline (42%) in area during the study period. The production and productivity was the lowest in 1982-83 (82kg/ha), followed by1983-84 (215kg/ha). In contrast, the maximum (6000t) cocoa production was recorded over Kerala in 2007-08 with lesser area. The trend was similar in the case of productivity, recording the maximum (570kg/ha) in recent years. As a whole, the study revealed that there was a sharp decline in cocoa area while increase in production and productivity.

It is a complex phenomena to workout relationship between rainfall and the cocoa production at the State level as the crop had undergone a market crisis in 1980s and 1990s and cocoa plantations were cut and replaced with other profitable crops like rubber. It was a neglected crop for long because of the low price in the market. Recently only, farmers started to take care of cocoa plantations on commercial angle. However, high rainfall appeared to be adversely affected the annual cocoa production of the State. For example, the annual rainfall recorded during 1994-95 was high (3183 mm) in which annual cocoa production was low (4300 t). It was also true in the case of 1997-98 (2887 mm), 1998-99 (3027 mm) and 1999-2000 (2898 mm) as the cocoa production during above the years was recorded as 3500, 3500 and 4000 tonnes, respectively (Table.26). In contrast, the annual cocoa production was more (6100 t) when the rainfall recorded was low (2481 mm) during 1985-86. Similar trend was also noticed during 1986-87 (2098 mm), 2003-04 (2259 mm) and 2004-05 (2571 mm) and cocoa production recorded was 6000, 5870 and 5900 tonnes, respectively. High rainfall, heavy cloudiness, low bright sunshine and high relative humidity appeared to be detrimental to cocoa. In the case of surface air temperature, it had influenced the annual yield negatively. For example, the annual cocoa production was less (3500 t) when mean temperature was high (28.1°C)

Table.26. Area, production and productivity of cocoa over Kerala

Year	Area (ha)	Production (tonnes)	Productivity (kg/ha)
1982-83	18200	1500	82
1983-84	18100	3900	215
1984-85	17900	4500	251
1985-86	16900	6100	361
1986-87	15000	6000	400
1987-88	14000	5900	421
1988-89	13600	5800	426
1989-90	12800	5200	406
1990-91	11900	4900	412
1991-92	10000	5400	540
1992-93	9300	5300	570
1993-94	8200	5300	646
1994-95	6900	4300	623
1995-96	7900	4300	544
1996-97	10200	5800	569
1997-98	8500	3500	412
1998-99	8500	3500	412
1999-00	8909	4000	449
2000-01	8500	4000	471
2001-02	8680	4100	472
2002-03	9295	5109	550
2003-04	10220	5870	574
2004-05	10220	5900	577
2005-06	10220	5400	528
2006-07	10520	5800	551
2007-08	10530	6000	570
Mean	11346	4899	462

Source: Directorate of Cocoa and cashew Development board

during 1998-99. Similar was the case in 1995-96 (27.9°C) when the production was low (4300 t). In contrast, the production was more (5800 t) during 1996 when the surface air temperature was low (27.7°C). It revealed that high summer temperature may be detrimental to cocoa production in the absence of soil moisture. The effect of rainfall and temperature was similar in the case of cocoa productivity also. These studies are highlighted in detail based on experimental data at farm level to understand the relationship of temperature and rainfall on cocoa much better.

4.7. Climate and cocoa yield over Vellanikkara

The annual pod yield during the study period from1991-2007 showed a declining trend, indicating that the yield potential of the trees came down year-after-year due to age of the trees. It was predominant after 2000 onwards (Table.27). The annual number of pods was low during 2004 (28.2 pods/tree), 1998 (40.4 pods/tree), 2002 (41.1 pods/tree), 2006 (41.1 pods/tree), 2003 (41.7 pods/tree) and 1995 (42.7 pods/plant) while more during 1993 (72.2 pods/tree), 1992 (68.2 pods/ tree), 1996 (66.1 pods/tree) and 1999 (59.6 pods/tree). The annual yield was intermediary in 1991 (46.3 pods/tree), 1994 (46.8 pods/tree), 1997 (54.7 pods/tree), 2001 (51.4 pods/tree), 2000 (44.4 pods/tree), 2005 (49.8 pods/tree) and 2007 (49.2 pods/tree).

Table.27. Monthly and annual cocoa yield at CCRP farm, Vellanikkara from 1991-2007

Year	No, of pods / tree												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1991	1.9	1.7	1.8	5.5	12.1	11.3	3.7	2.4	1.1	1.1	2.4	1.4	46.3
1992	2.0	2.8	2.4	7.3	10.6	7.6	12.1	6.9	5.4	4.7	5.8	0.7	68.2
1993	2.5	2.4	2.3	2.5	6.1	15.3	13.8	10.9	7.0	1.4	3.4	4.8	72.2
1994	3.9	6.7	3.3	2.7	6.6	3.1	4.7	2.2	6.7	6.8	0.0	0.0	46.8
1995	1.4	2.9	8.9	1.5	6.5	5.4	0.0	6.2	0.0	4.8	0.0	5.1	42.7
1996	5.1	1.9	5.7	5.0	5.0	8.0	2.5	0.0	7.1	10.3	6.9	8.8	66.1
1997	7.4	2.4	2.1	1.1	9.0	2.4	13.9	3.6	4.2	1.3	3.6	3.8	54.7
1998	6.0	2.4	6.0	5.0	6.8	0.0	1.3	4.6	2.9	0.7	3.1	1.6	40.4
1999	6.8	6.6	3.7	0.0	8.3	0.8	1.7	3.6	3.9	4.9	14.3	5.0	59.6
2000	3.0	4.6	0.0	4.6	15.1	0.0	2.6	2.8	2.9	0.0	8.0	7.8	51.4
2001	6.4	0.0	4.3	3.1	3.8	1.1	1.4	4.7	3.6	5.1	5.2	5.8	44.4
2002	8.4	3.3	1.7	4.2	4.7	0.6	0.6	0.6	2.1	4.4	3.9	6.5	41.1
2003	6.2	0.6	4.2	7.2	5.9	0.9	0.9	2.4	5.5	1.1	0.9	5.8	41.7
2004	4.0	2.4	3.0	3.3	0.0	1.32	1.0	0.1	4.8	3.4	4.8	0	28.2
2005	4.3	2.7	9.7	4.2	4.5	4.3	2.5	0.5	3.2	11.8	1.2	1.0	49.8
2006	1.8	1.6	8.8	0.0	0.0	3.7	0.0	8.7	4.4	2.1	3.1	6.8	41.1
2007	6.7	1.3	20.5	5.4	0.0	1.3	1.5	0.2	0.7	5.9	4.3	1.5	49.2
Mean	4.6	2.7	5.2	3.7	6.1	3.9	3.8	3.6	3.9	4.4	4.2	3.9	49.9
Std.Dev	2.2	1.8	4.8	2.2	4.1	4.3	4.7	3.2	2.1	3.3	3.4	2.9	11.5
CV (%)	48.9	66.5	92.7	59.7	67.0	110.2	124.3	88.6	54.9	74.6	82.6	73.1	23.0

The mean peak harvest was noticed during May (6.1 pods/tree), followed by March (5.2 pods/tree) while less in February (2.7/tree). The coefficient of variation was very high (48.9-124.3 %) in monthly pod yield of cocoa while it was less (23 %) in the case of annual yield of cocoa. It indicated that the monthly cocoa yield is very sensitive to extreme weather conditions unlike in the case of annual yield. The cocoa yield is also highly variable during the rainy season (June-August) as the coefficient of variation is very high, varying between 88.6 and 124.3 per cent. It also showed no significant difference between alternate years, indicating that cocoa is a regular yielder with no biennial bearing tendency (Table.28). It reveals that the inter-annual variation of cocoa yield could be attributed to weather aberrations.

Table.28. Annual cocoa yield in alternate years

Odd years		Even years	
Years	Yield (pods/tree)	Years	Yield (pods/tree)
1991	46.3	1992	68.2
1993	72.2	1994	46.8
1995	42.7	1996	66.1
1997	54.7	1998	40.4
1999	59.6	2000	51.4
2001	44.4	2002	41.1
2003	41.7	2004	28.2
2005	49.8	2006	41.1
2007	49.2	-	-
Mean	51.2	Mean	47.9
Student t Value = 0.28; not significant			

The mean seasonal pod yield was more during the summer (5.0 pods/tree), followed by post monsoon season (4.2 pods/tree). The number of pods harvested during winter was low (3.7 pods/tree). It reveals that the pod yield was more during summer, contributing 29.9 % to the annual yield (Table.29), followed by post monsoon season (25.1 %).

Table.29. Annual and seasonal pod production of cocoa at CCRP farm, Vellanikkara from 1991-2007

Year/Season	Yield (pods/tree)								Annual (pods/tree)
	Winter (Dec-Feb)		Summer (Mar-May)		Southwest monsoon (June-Sep)		Post monsoon (Oct-Nov)		
	Mean	%	Mean	%	Mean	%	Mean	%	
1990-91	5.2	11.1	19.4	41.6	18.5	39.8	3.5	7.5	46.6
1991-92	6.1	8.9	20.2	29.5	32	46.5	10.4	15.1	68.7
1992-93	5.6	8.3	10.9	16	46.9	68.7	4.8	7	68.2
1993-94	15.5	30	12.6	24.4	16.7	32.4	6.8	13.2	51.6
1994-95	4.3	11.3	16.9	45	11.6	30.7	4.8	13	37.6
1995-96	12.1	19.4	15.7	25.1	17.6	28.1	17.1	27.4	62.5
1996-97	18.6	31.1	12.2	20.5	24	40.2	4.9	8.2	59.7
1997-98	12.1	28.6	17.8	41.9	8.8	20.7	3.8	8.8	42.5
1998-99	15	26.8	12	21.3	9.9	17.7	19.2	34.2	56.1
1999-2000	12.6	26	19.7	40.5	8.3	17.1	8	16.4	48.6
2000-01	14.1	30.5	11.1	24.1	10.8	23.3	10.2	22.1	46.2
2001-02	17.5	43.3	10.6	26.2	4	9.9	8.4	20.6	40.5
2002-03	13.3	31.5	17.3	40.8	9.7	22.8	2.1	4.9	42.4
2003-04	12.1	35.7	6.3	18.6	7.3	21.4	8.3	24.3	34
2004-05	7	14.3	18.4	37.7	10.4	21.4	13	26.6	48.8
2005-06	4.5	12.7	8.8	25.1	16.8	47.5	5.2	14.7	35.3
2006-07	14.8	27.2	25.8	47.4	3.7	6.7	10.2	18.7	54.5
Average	11.2	22.6	15.0	30.3	15.1	30.4	8.3	16.7	49.6
Seasonal Mean	3.7	22.2	5.0	29.97	3.8	22.8	4.2	25.1	16.7
Std.Dev	4.8		5.0		10.9		4.7		10.7
CV (%)	42.4		33.3		72.2		57.3		21.7

The percentage of pods recorded was low (22.2 %) during winter and southwest monsoon (22.8 %). High monthly variation in cocoa yield was nullified to some extent when the seasonal variations in yield were taken into account as the seasonal coefficient of variation was relatively less (33.3-72.2 %) when compared to that of monthly coefficient of variation (48.9-124.3 %).

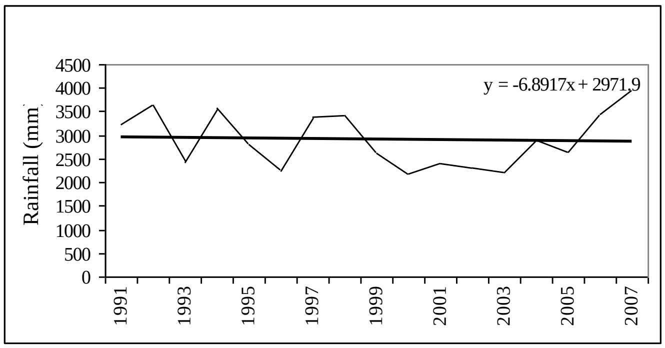
4.7.1 Climate variability and cocoa yield:

A decline in annual rainfall at the rate of 6.9 mm/year was noticed during the study period from 1991-2007 (Fig.4). Similar trend was noticed in southwest monsoon (11.4 mm/year) and post monsoon season (11.2 mm/year). In winter, no declining trend in rainfall was noticed. In contrast, a sharp increase (20.3 mm/year) was noticed in summer rainfall. It could be attributed to decline in number of rainy days in all the seasons except in summer during which increase was noticed. In the case of surface air temperature, the maximum temperature was declining (0.03°C/year) during the study period (1991-2007) while increase in night temperature (0.005°C/year). Decrease in maximum temperature (0.03°C/year) and increase in night temperature led to a declining trend in temperature range (difference between maximum and minimum temperature). The annual maximum temperature was the highest in 1991 (32.5 °C) and 1995 (33.0 °C) while minimum temperature in 1998 (23.7 °C), followed by 1996 (23.6 °C) and 2003 (23.6 °C). Warm winters (0.004°C/year) and cool summers (0.07°C/year) are likely in ensuing years at Vellanikkara as per the present trends.

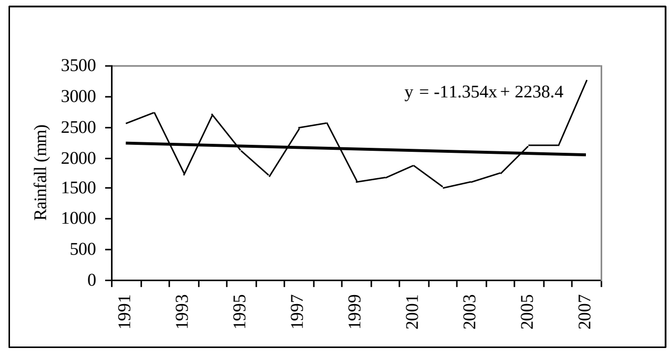
There was an inverse trend between the annual rainfall and cocoa yield (Fig.5). Whenever the annual rainfall was very high, the annual cocoa yield was low. For example, the annual rainfall recorded was high (3579mm) in 1994 against the normal (2803mm) and the yield during the year was low (46.8 pods/year). Similar trend was also noticed during 1998 (40.4 pods/tree), 2004 (28.2 pods/tree) and 2006 (41.1 pods/tree) during which the annual rainfall was 3435mm, 2895mm and 3460mm, respectively. Whereas in 1993, 1996, 1999, and 2000, the annual rainfall recorded was relatively less (2439mm, 2241mm, 2619mm and 2173mm respectively) as against the normal and the annual cocoa yield during the above years was (72.2 pods/tree, 66.1 pods/tree, 59.6

Fig.4. Trend in different weather variables at Vellanikkara from 1991-2007

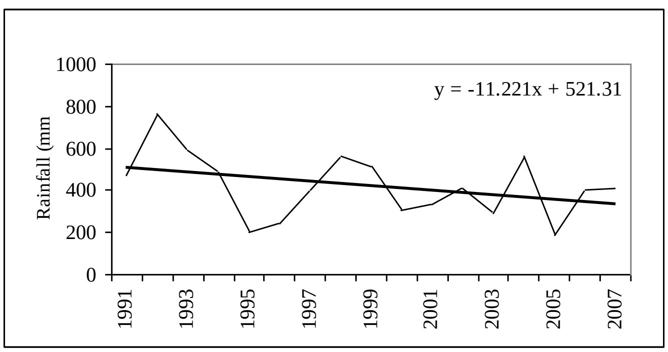
Trend in annual rainfall from 1991-2007



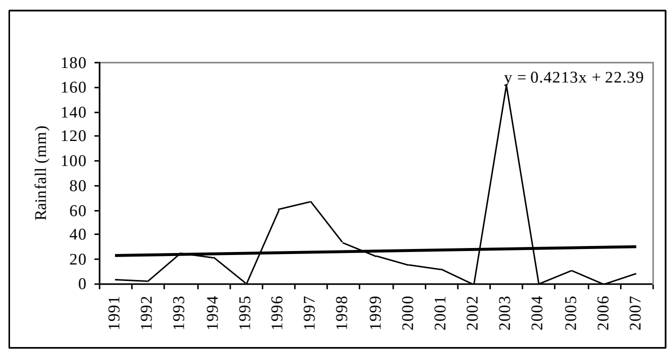
Trend in southwest monsoon rainfall from 1991-2007



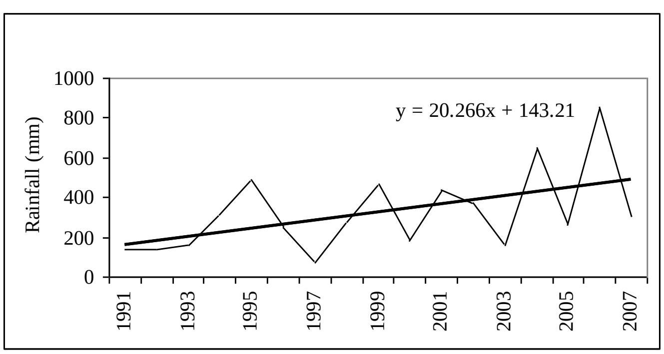
Trend in post monsoon rainfall from 1991-2007



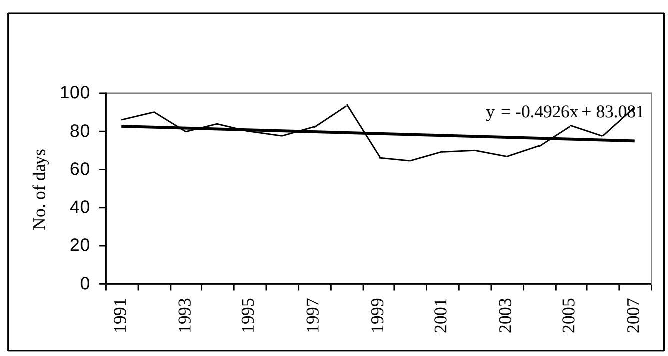
Trend in winter rainfall from 1991-2007



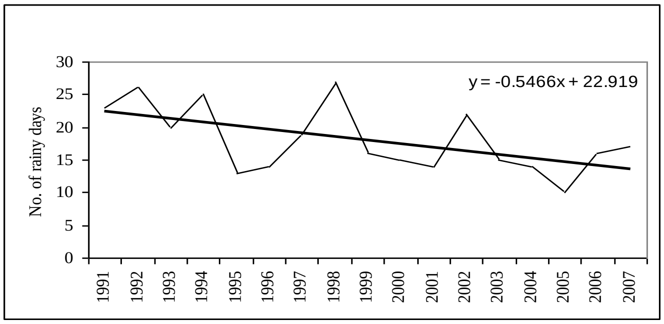
Trend in summer rainfall from 1991-2007



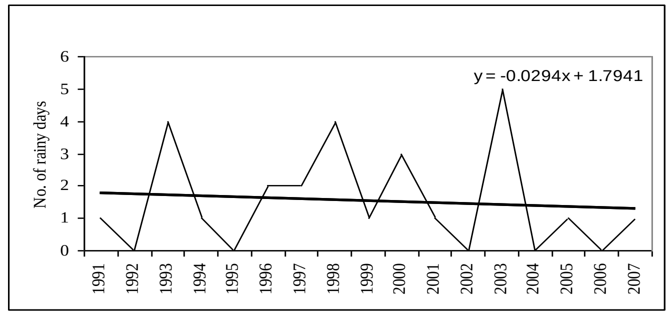
Trend in number of rainy days during SWM from 1991-2007



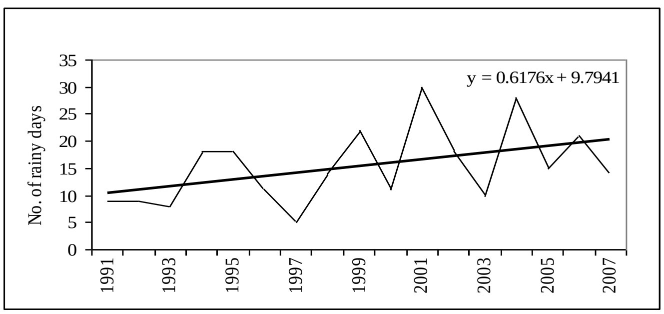
Trend in rainy days during post monsoon season from 1991-2007



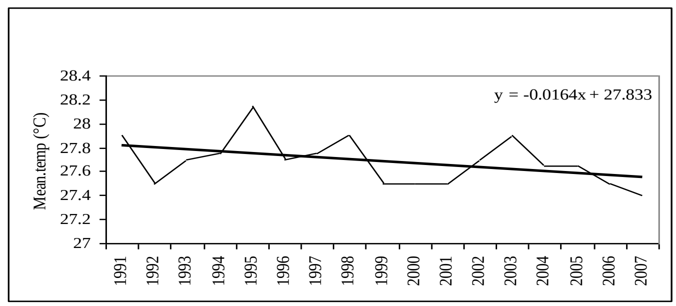
Trend in rainy days during winter from 1991-2007



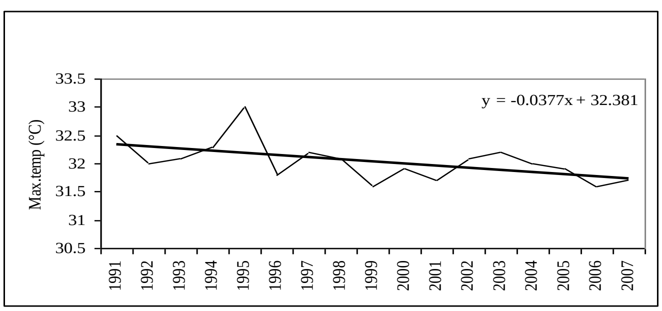
Trend in number of rainy days during summer from 1991-2007



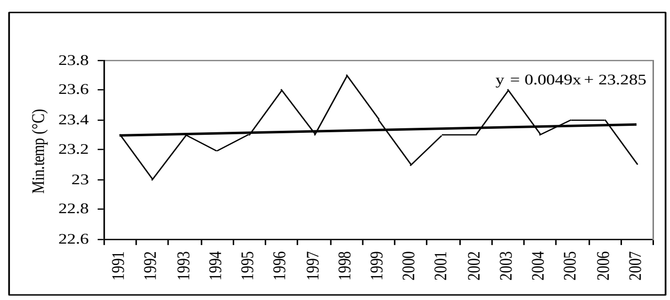
Trend in mean temperature from 1991-2007



Trend in maximum temperature from 1991-2007



Trend in minimum temperature from 1991-2007



Trend in temperature range from 1991-2007

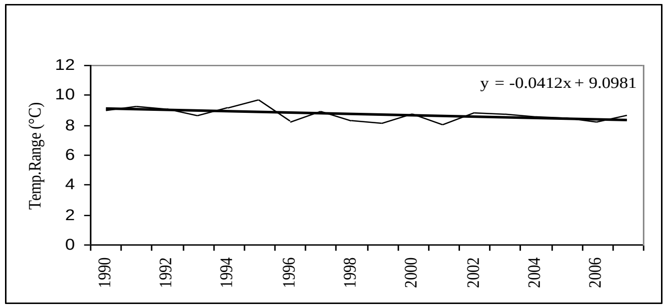
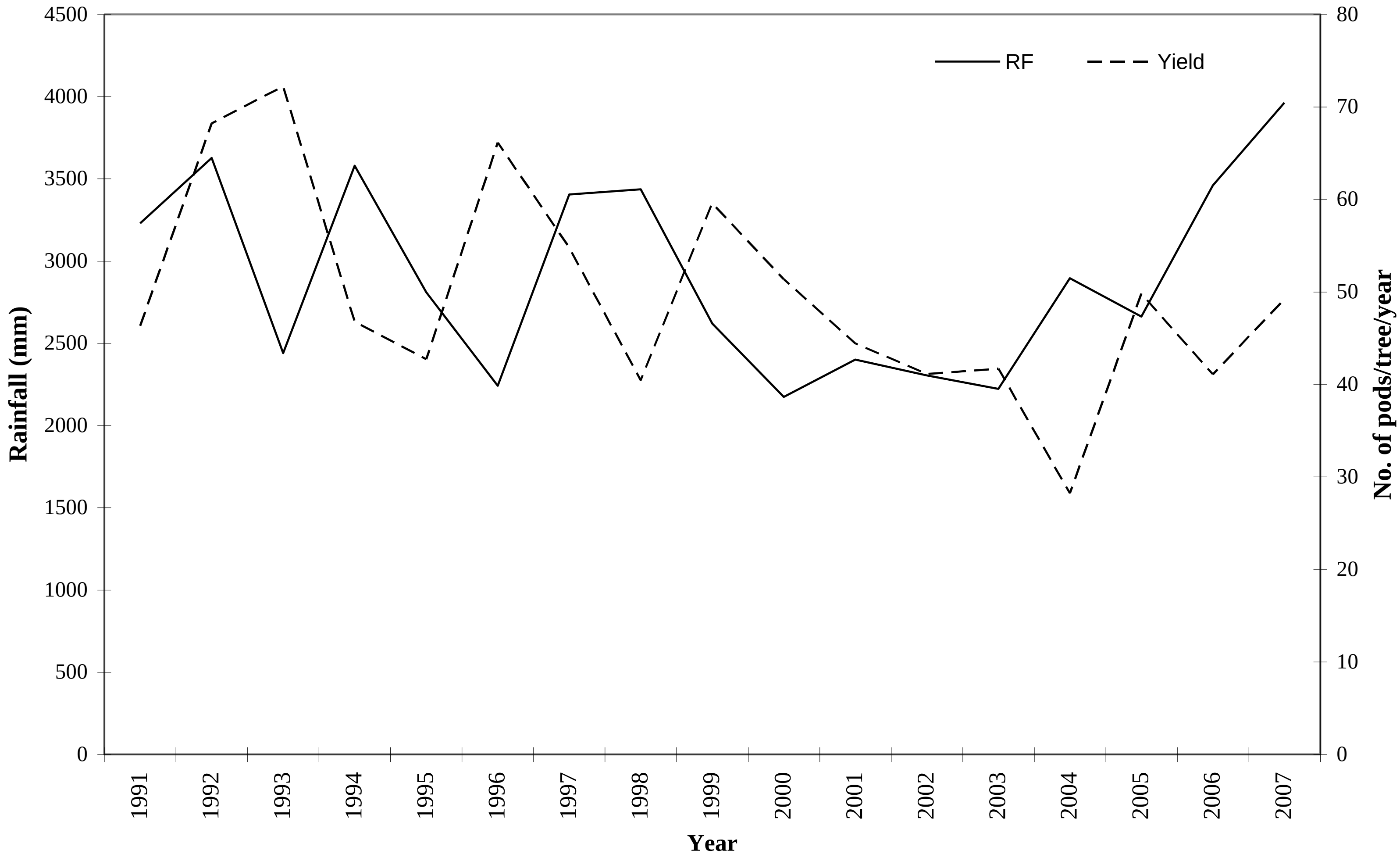


Figure.5 Annaul rainfall and cocoa yield from 1991-2007 at Vellanikkara



pods/tree, and 51.4 pods/tree, respectively). It revealed that the annual cocoa yield was relatively low when the annual rainfall was high against the normal rainfall and *vice-versa*. The relationship between mean annual soil moisture and yield also indicated similar trend as in the case of rainfall. For example, the mean annual soil moisture recorded during 2003 was high (16.5 %) and the yield during the year was low (41.7 pods/tree). It was also true during 2001, 2004 and 2006 (Fig.6) as the annual cocoa yield was low and recorded as 44.4 pods/tree, 28.2 pods/tree and 41.1 pods/tree, respectively. In contrast, the yield recorded during 1999 (66.1 pods/tree) and 2005 (49.8 pods/tree) was high during which annual soil moisture was low and recoded as 11.4 % and 11.1 %, respectively. The same trend between the soil moisture and yield was reflected as in the case of rainfall. As the soil moisture is dependant on rainfall such relationship is expected. High rainfall lead to heavy soil moisture which may result in waterlogging or sometimes flood the fields where cocoa is grown. It is detrimental to cocoa crop. As the yield pattern shows peak during summer, it had a negative relationship with soil moisture since it is minimal in the absence of rain during summer. In fact, any improvement in soil moisture during summer may result in good health of plant, in turn lead to better yield.

In the case of temperature, the maximum temperature from January to March had a profound influence on annual cocoa yield (Fig.7). Whenever there was an increase in maximum temperature, the annual cocoa yield recorded was low. For example, the maximum temperature recorded between January and March was high (35.3 °C) in 1995 against the normal (34.6 °C) and the annual cocoa yield was low (42.7 pods/tree). It was also true during 2004 (35.0 °C) in which low yield (28.2 pods/tree) was obtained. Whereas, the maximum temperature recorded in 1993 was low (34.0°C) and the annual cocoa yield was high (72.2 pods/tree). Similar was the case in 1997 and 2000 as the annual cocoa yield during the above years were 54.7 pods/tree and 51.4 pods/tree, respectively. The relationship between growing degree days (GDD) and yield also indicated similar trend as in the case of maximum temperature (Fig.8). For example, the GDD recorded during 1995 was high (6606°C) and the yield during the year was low (42.7 pods/tree). It was also true during 1998 (6533°C) and 2003 (6533°C) as the annual cocoa yield was low and recorded as 40.4 pods/tree and 41.7 pods/tree,respectively.In

Figure.6 Soil moisture (30cm depth) and cocoa yield from 1998 to 2007 at Vellanikkara

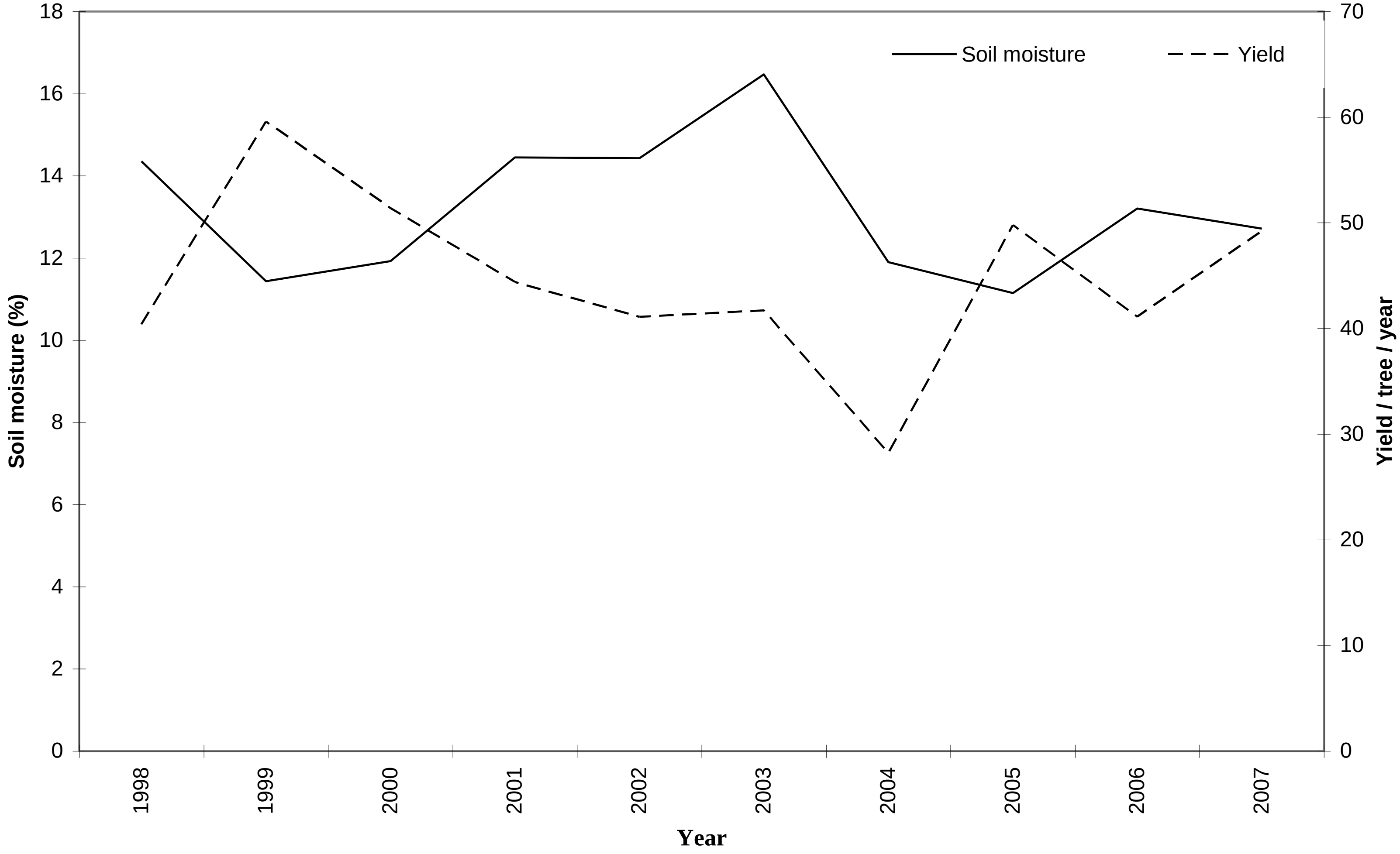


Figure.7 Maximum temperature from January to March and annual pod yield of cocoa from 1991-2007 at Vellanikkara

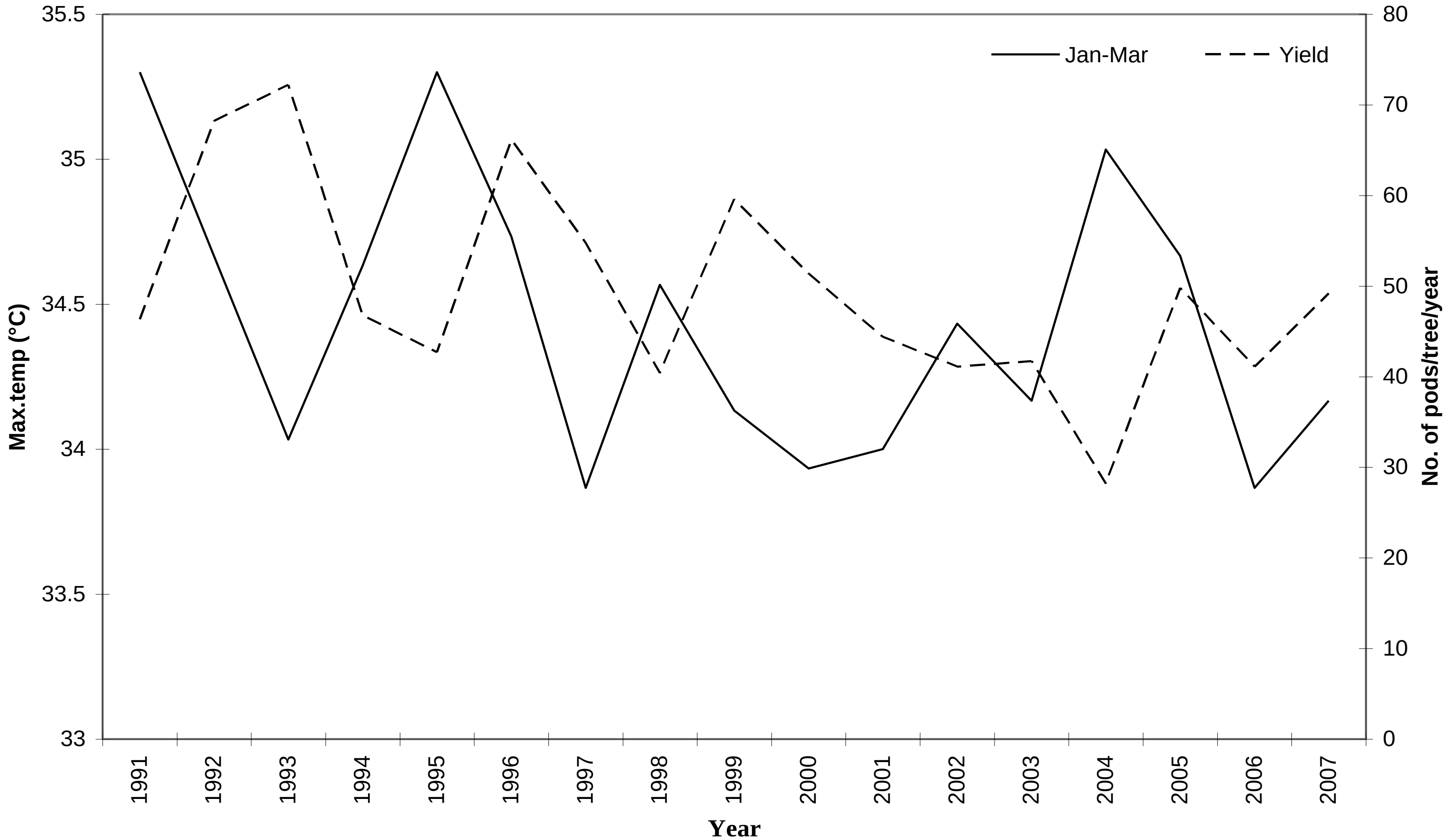
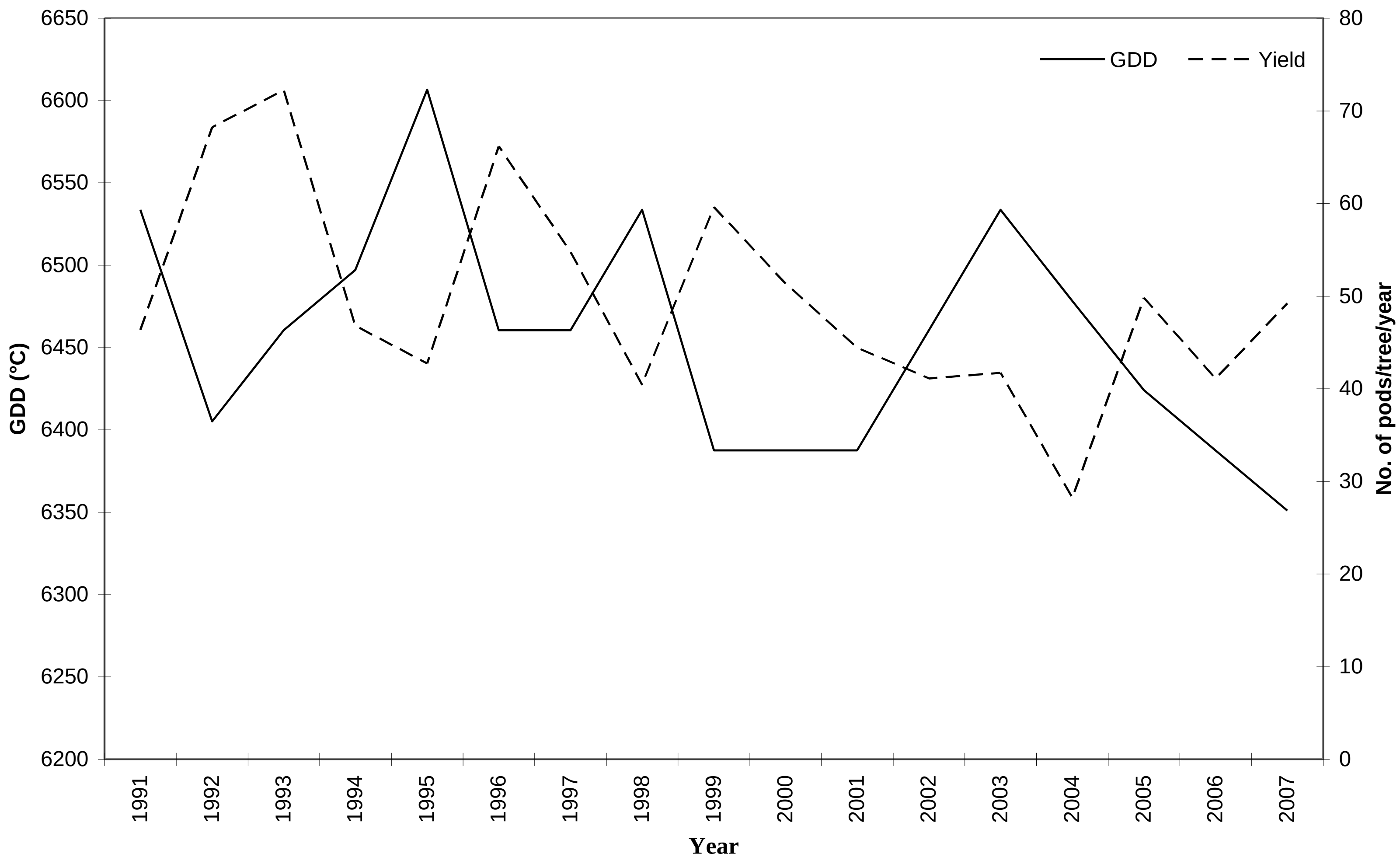


Figure.8 Annual Growing Degree Days and cocoa pod yield from 1991-2007 at Vellanikkara



contrast, the yield recorded during 1992 (68.2 pods/tree), 1993 (72.2 pods/tree) and 1996 (66.1 pods/tree) was high during which low GDD was recorded viz, 6405°C, 6460°C and 6460°C, respectively. On examination of good and bad yield years, it was found that the difference in cocoa yield during rainy months was very significant followed by post monsoon season against the normal when compared to that of other seasons. On an average, the decline in yield was 45 per cent in bad yield years when compared to the mean yield while 45 per cent increase in good yield years during the southwest monsoon and post monsoon when compared to that of normal (Table.30).

Table.30 Cocoa yield (pods/tree) during southwest monsoon and post monsoon in good and bad yield years

Months	Pod yield in good years	% increase in yield	Pod yield in bad years	% reduction in yield
June	7.9	51	1.6	59
July	7.5	49	0.9	76
August	5.4	33	2.5	31
September	5.9	34	2.7	31
October	5.3	20	2.8	37
November	7.6	80	2.6	38
Mean	6.6	45	2.2	45

The percentage increase in yield during good years when compared to that of bad years was 72 and 58 per cent during southwest monsoon and post monsoon, respectively. Interestingly, there was no yield difference between good and bad yield years during winter while increase in summer was only 13 per cent (Table.31).

Table.31 Seasonal cocoa yield (pods/tree) in good and bad yield years

Seasons	Yield in good years	Yield in bad years	% increase in good years
Summer	4.5	3.9	13
Southwest monsoon	6.7	1.9	72
Post monsoon	6.5	2.7	58
Winter	4.5	4.5	0

The maximum temperature during summer was high (34.7°C) in poor yield years while less (34.2°C) in good yield years. A mean maximum difference of 1.1°C was noticed in April between good and poor yield years (Table.32). It revealed that high maximum temperature during summer with heavy rainfall during rainy season is likely to affect the annual cocoa yield adversely.

Table.32 Monthly maximum temperature during summer in good and bad yield years

Months	Max.temp in Good yield years (°C)					Max. temp in bad yield years (°C)				Normal (°C)
	1992	1993	1996	1999	Mean	2004	1998	1995	Mean	
January	32.6	32.7	33.1	32.4	32.7	33.4	33.1	32.9	33.1	32.8
February	34.4	34.1	34.7	34.5	34.4	35.2	34.4	35.4	35.0	34.8
March	36.9	35.4	36.4	35.5	36.1	36.5	36.2	37.6	36.8	36.1
April	36.3	35.6	34.6	33.4	34.9	34.8	36.5	36.6	36.0	35.4
May	33.8	34.4	32.8	30.7	33.0	30.4	34.2	33.5	32.7	33.8
Mean	34.8	34.4	34.3	33.3	34.2	34.1	34.9	35.2	34.7	34.5

Results of the simple correlation analysis between weather parameters zero to 6 months before pod production and number of pods are presented in Table 33. Out of the five weather variables, maximum and minimum temperatures and rainfall had significant relationship with pod production. There was no significant relationship between temperature range, number of rainy days and pod production. Maximum temperature had a positive significant relationship with pod production two months (0.143) prior to pod production. It reflected on number of growing degree days also. The minimum temperature had both positive and negative significant relationship with the pod production. It had positive significant relationship during the month (0.154) of pod production and had negative relationship during five months prior (-0.179) to pod production. Rainfall had recorded a negative significant correlation with the pod production two months (-0.140) prior to pod production.

Table.33 Relationship between weather variables of 0 to 6 months before pod production and pod production

Months	Max.temp	Min.temp	Temperature Range	GDD	Rainfall	Rainy days
0	0.095	0.154*	0.037	0.129	-0.041	-0.049
1	-0.025	0.113	-0.058	0.021	-0.038	-0.083
2	0.143*	-0.069	0.126	0.140*	-0.140*	-0.126
3	0.041	-0.084	0.080	0.006	-0.052	-0.078
4	-0.020	-0.109	0.025	-0.052	-0.063	-0.072
5	-0.076	-0.179*	-0.006	-0.121	-0.048	-0.022
6	-0.047	-0.070	-0.021	-0.061	-0.027	-0.011

** Correlation significant at 0.01 level; * Correlation significant at 0.05 level

It shows that rainfall had negative correlation with annual yield while positive correlation with the maximum temperature two weeks prior to pod production. It is a clear indication of multicollinearity among rainfall and maximum temperature and showed opposite correlation with annual cocoa yield. Interestingly, rainfall had negative correlation throughout the pod development period (0-6 months), initiated from pod set to harvest. It is evident that high rainfall in the humid tropics may not be conducive for obtaining better yield in cocoa. High rainfall may result in waterlogging, less bright sunshine, heavy cloudiness and high relative humidity. These factors may in turn lead to immature fruit drop during its developmental phase and heavy disease incidence in cocoa like pod rot. The incidence of pod rot may damage the crop to a considerable extent. It might be one of the reasons for high variation in monthly cocoa yield. It indicated that the weather variables such as heavy rainfall during rainy period and high maximum temperature during summer had direct and indirect adverse bearing impact on cocoa yield.

Discussion

5. DISCUSSION

The present investigation was taken up with a view to determine the effect of various weather elements on growth biotic events (Flowers, pod set and cherelle) and yield of cocoa. The results of the experiments detailed in the previous chapter are discussed here under.

5.1. Pattern of flowering:

Cocoa exhibited flowering round-the-year though weekly variations were significant and almost no flowers were recorded in August, unlike majority of plantation crops in which flowering is seasonal. In the present investigation, the period of flowering was found from November to May. The peak flowering was seen during summer (February-May) while less from June to October. It revealed that the flowering commences by the end of October while ceases with commencement of heavy rain by the middle of June, indicating that the flowering pattern follows the pattern of rainfall. Heavy rainfall was noticed from June to October, followed by a prolonged dry spell from November to May except few summer showers (Fig.9). The pattern of rainfall is a peculiar one in the humid tropics, where cocoa is grown. It is one of the reasons, why, the pattern of cocoa flowering is similar irrespective of shade and open with different yield groups. However, the number of flowers produced was more during the peak flowering period of cocoa under relatively open conditions (Fig.10). In the present investigation, it is observed that the light availability on an average over cocoa under rubber (shade) was only 45 per cent, varying from 39 % (October) to 56 % (April). The intensity of light availability varied from 10996 (September) to 22103 lux (May) in cocoa under the shade while it was 27293 (April) to 45177 lux (May) in open (Table.34).

Figure.9 Weekly mean number of flowers and rainfall from April 2007 to March 2008

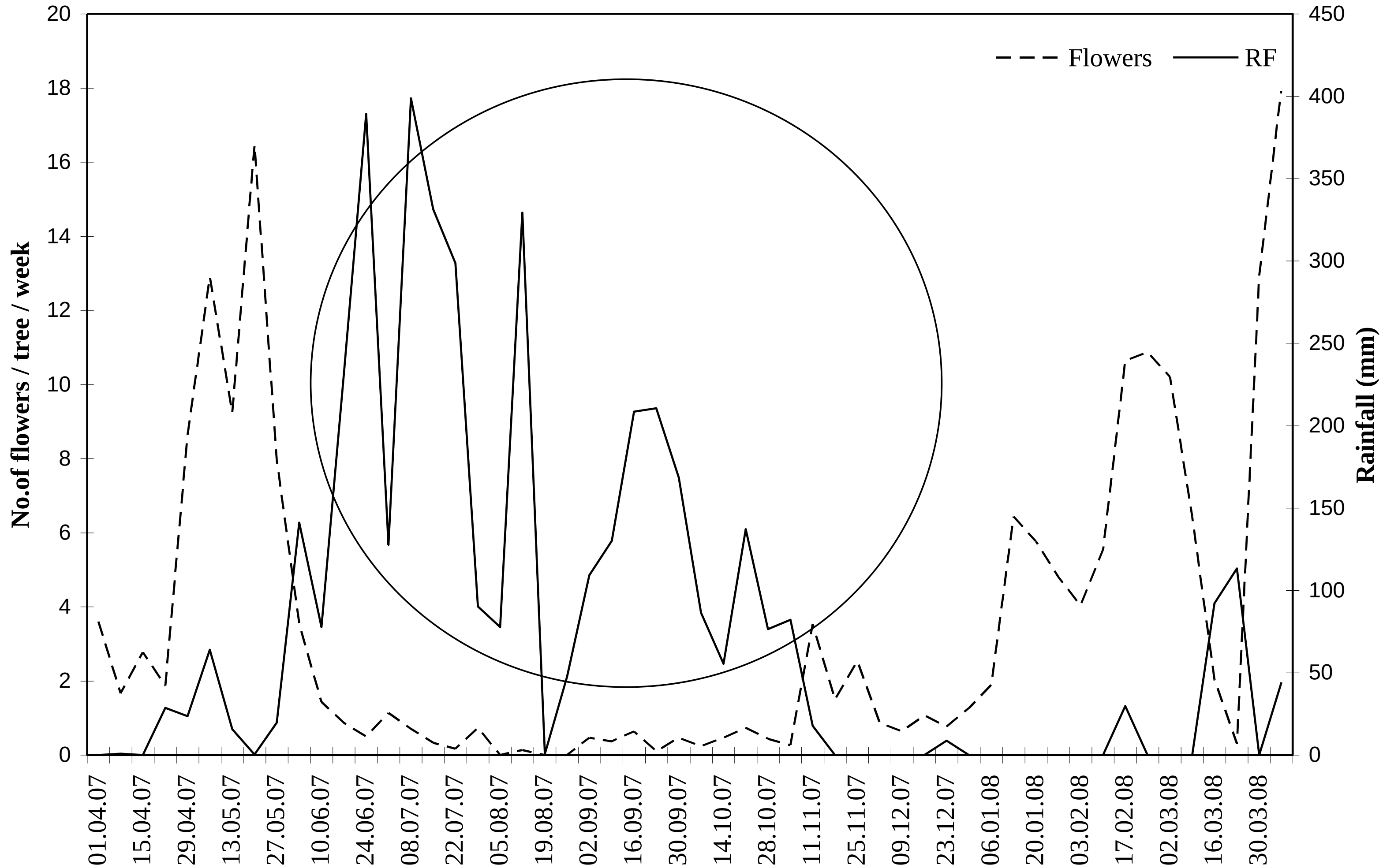


Figure.10. Weekly mean number of flowers in open and shade at vellanikkara from April 2007 to March 2008

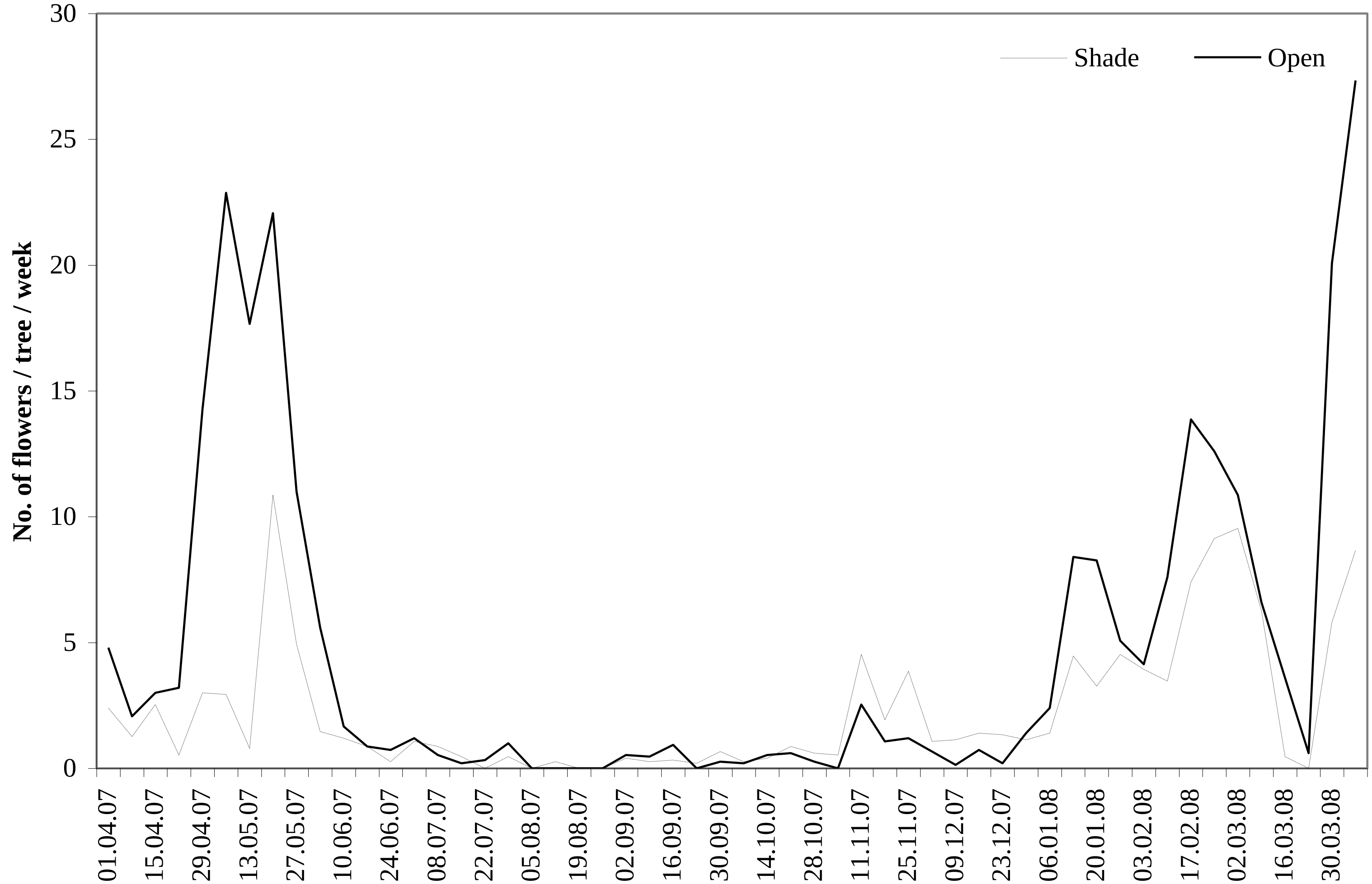
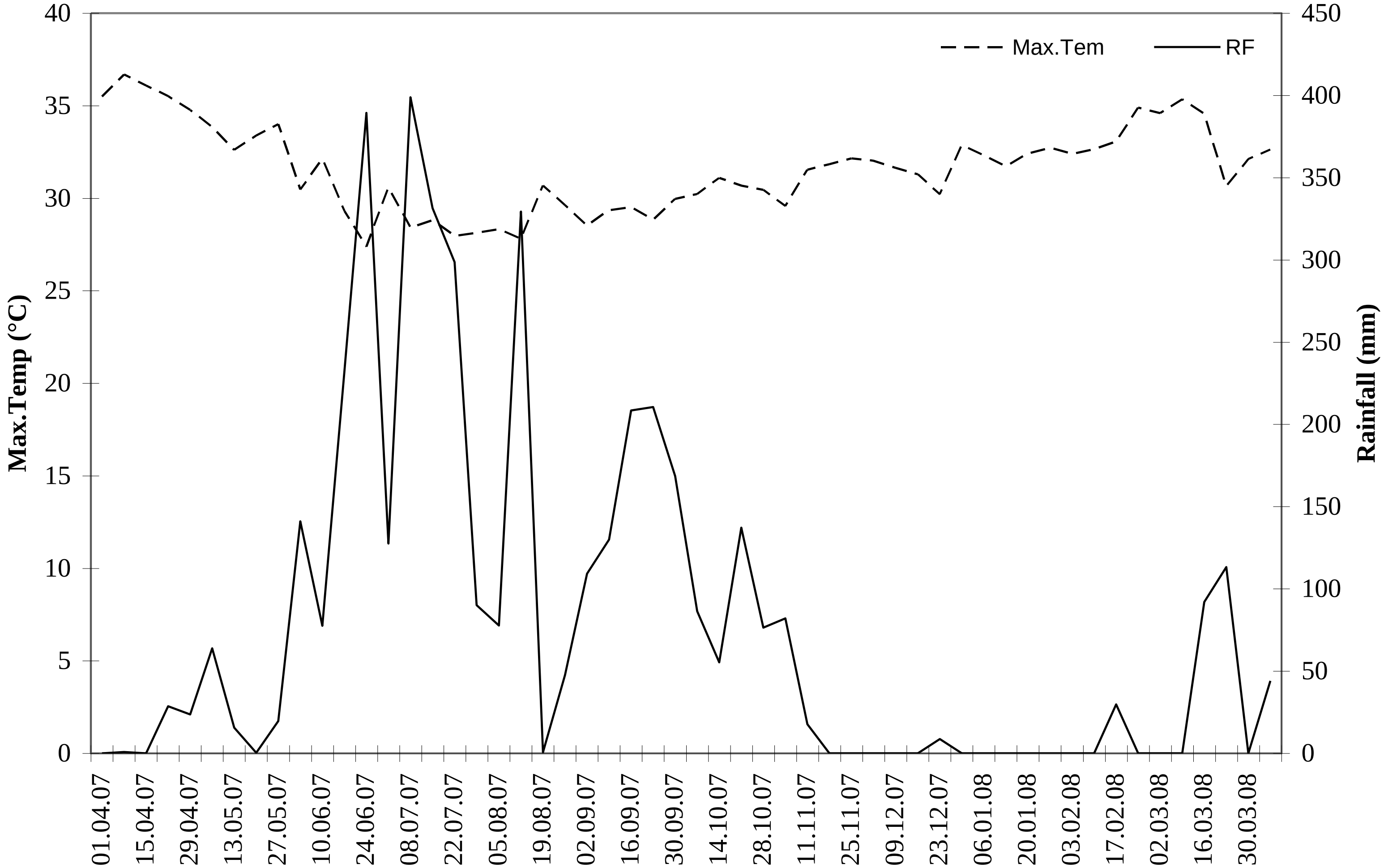


Table.34. Light availability (lux) and shade percentage in cocoa grown under rubberduring different mo

Months	Available light (lux)	Light (%)	Shade (%)
April	16121	56	44
May	22103	38	62
September	10996	43	57
October	18223	39	61
November	20556	47	53
December	19498	46	54
January	17039	46	54
February	17055	41	59
March	17986	47	53
Mean	17731	45	55

The inter-relationship among various weather variables indicated that rainfall had significant negative correlation with maximum temperature, bright sunshine while positive correlations with morning and afternoon relative humidity and rainy days. Due to multi-collinearity effect, the flower production had significant positive relationship with maximum temperature and bright sunshine while significant negative correlation with morning and afternoon relative humidity, rainfall and rainy days. The correlations between rainfall and flowering indicated that rainfall had negative (-0.464) relationship with flowering as no significant flowering was seen during the heavy rainfall period from June-October. At the same time, it had a positive (0.763) correlation with summer rains two weeks prior to flowering. From the above, it is clear that the flowering appears to be very low during the heavy wet spell due to mechanical damage as well as low bright sunshine available to the crop. Nevertheless, the summer rains between February and May influenced the flowering favourably. The weekly rainfall versus maximum temperature showed that there was a significant dip in maximum temperature from June to October during heavy rainy season (Fig.11). In the absence of rains from November to May, the maximum temperature revolves around 35 to 37^{o}C during summer (February-May) while it revolved around 28-30^{o}C during the rainy months. It is one of the reasons, why, the flowering had positive correlation with maximum temperature when it had

Figure.11. Maximum temperature and rainfall from April 2007 to March 2008



negative correlation with rainfall. Similar was the case with bright sunshine (negative correlation) and relative humidity (positive correlation). Because of multi-collinearity effect among the various weather variables, it is a complex phenomena to find out relationship through correlations between weather variables and flowering other than rainfall as rainfall influenced the other weather variables under the humid tropics. It can be stated that the positive relationship of cocoa flowering with maximum temperature was only due to flowering pattern of cocoa but not due to high maximum temperature that prevailed during the summer. The optimum maximum temperature for flowering of cocoa may be around 30-32^{o}C, while the summer temperature shot up to 35-37^{o}C during peak summer where cocoa is grown. According to Wood (1985), a minimum range of 18^{o}C to 21^{o}C and a maximum of 30^{o}C - 32^{o}C limited the cocoa belt. Asopa and Narayanan (1990) reported a shade temperature between 13^{o}C and 35^{o}C as the optimum range for growth. The optimum range of mean monthly temperature of cocoa growing region is 15-32^{o}C. Keeping the above in view, the thermal indices were worked out to find out the relationship between temperature and flowering. There was a close relationship between the helio-thermal units (HTU) and flowering behaviour in cocoa and significant at 0.01 level. The helio-thermal units depend on growing degree days, which is a function of temperature [(Max+Min/2)-10^{o}C] and number of daily sunshine hours. It indicates that the flowering behaviour of cocoa responds not only to rainfall and its distribution but also to the availability of helio-thermal units.

Alvim (1968) described excessive rainfall with waterlogging from September, 1967 to March, 1968, and lower than average temperature as the reasons for reduced flowering during the season. Describing flowering and fruit setting patterns of cocoa trees at three localities in Costa Rica, Young (1984) reported a marked decline in flowering near the end of the rainy season when rainfall was very high. Based on the studies on flowering, Alvim et al. (1972) had reported that the major determinant in flower production of Brazilian cocoa was "relief from strains". High temperature, dry spell and continuous wet conditions were indicated as some factors contributing to strain. Such a relief from strain resulting often from receipt or cessation of rains was reported to lead to flushing and flowering follows just as leaves hardened. Under Brazilian conditions, the time lag is about two months between incidence of rainfall and the emergence of flowering. In contrast, it is observed that the time lag between receipt of rain and appearance of flowers is only to the extent of two weeks during summer when cocoa is under severe soil moisture stress (Fig.12). It is in confirmation with the studies conducted by Prameela (1997). It is stated that, there was a lag period of 10-21 days between flower production and summer rainfall. However, there was a cumulative effect of weather variables from 0 to 12 on flowering behaviuor and thus such lag period could not be worked out where cocoa is grown under continuous wet spell during rainy season for about four to six months followed by prolonged dry spell for remaining months during summer. It is also understood that the flowering pattern of cocoa in different countries situated in Northern Hemisphere followed a same pattern as the peak flowering was seen during summer. In Ghana, the peak period was from March-July (Hewison and Ababio, 1929), in Bahia from October to May (Alvim, 1966) and in Cuba from June-September (Delpinalrivero and Acunagale, 1967). The present study supports the view that the variations in flowering period across the Northern Hemisphere can be attributed to distribution of rainfall, temperature and the day length as it varied from one location to another within the season during summer (March-September). If that is the case, Hopkins bioclimatic law (1938) holds good in time of flowering in different countries across the Northern Hemisphere. It can be stated as "A biotic event in North America will, in general, show a lag of four days for each degree of latitude, five degree of longitude and 400 feet of altitude, northward, eastward and upward in spring and early summer". In the case of cashew and mango, the time lag with latitude was well established as per the above bioclimatic law (Rao, 2002). It can be tested in the case of cocoa also.

5.2. Pod set:

Pod set of cocoa seen round-the-year though weekly variations were significant and almost no pod set were recorded in August. In the present investigation, the period of pod set was found from November to May. The peak pod set was seen during summer (February-May) while less from June to October. It revealed that the pod set commences by the end of October while ceases with commencement of heavy rain by the middle of June, indicating that the pattern of pod set follows the pattern of rainfall. It is one of the reasons, why, the pattern of pod set in cocoa was similar irrespective of shade and open with different yield groups. However, the number of pod set was more under relatively open conditions (Fig.13).

Figure.12 Summer rainfall two weeks before flower production and flower production during summer

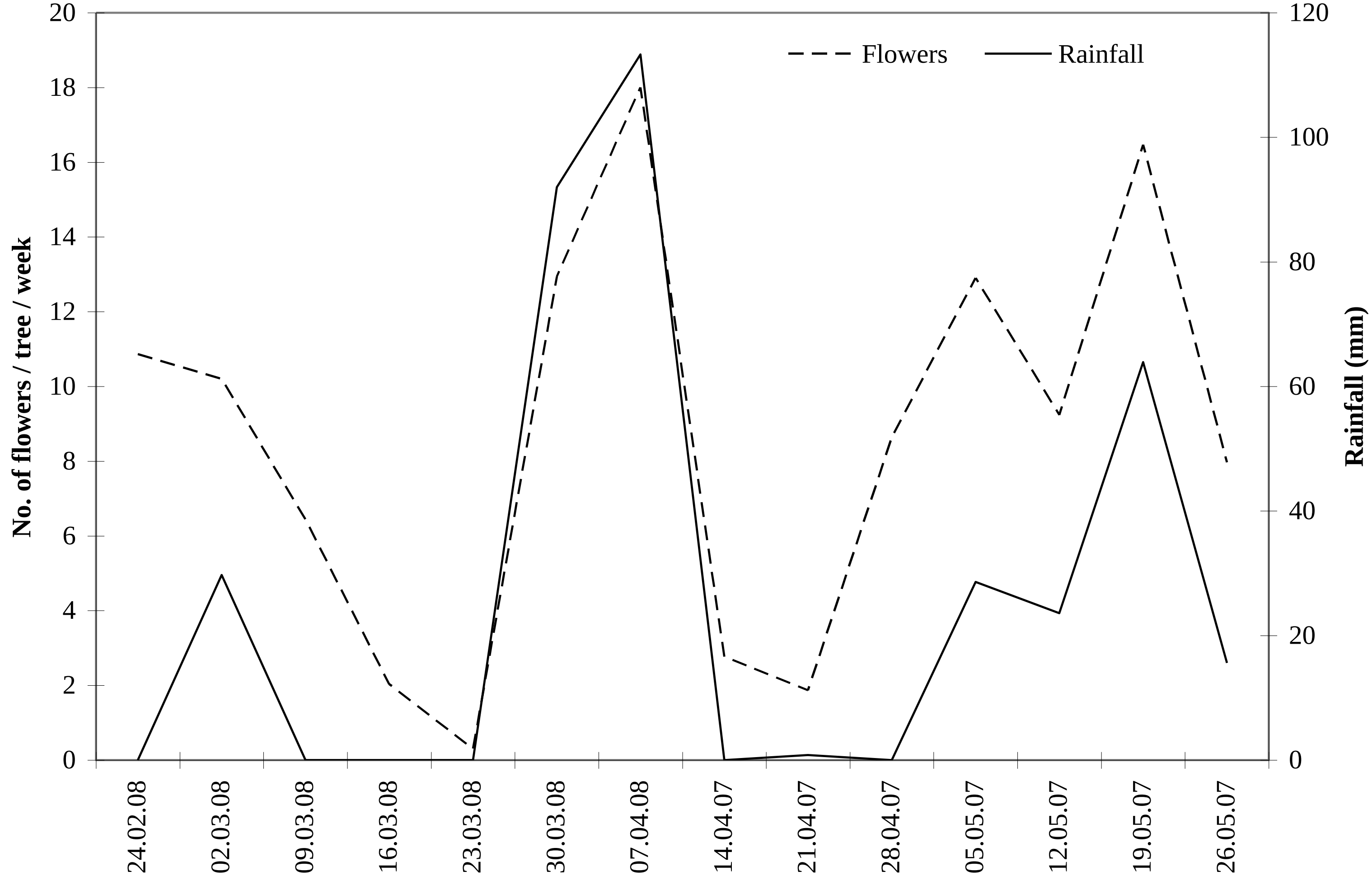
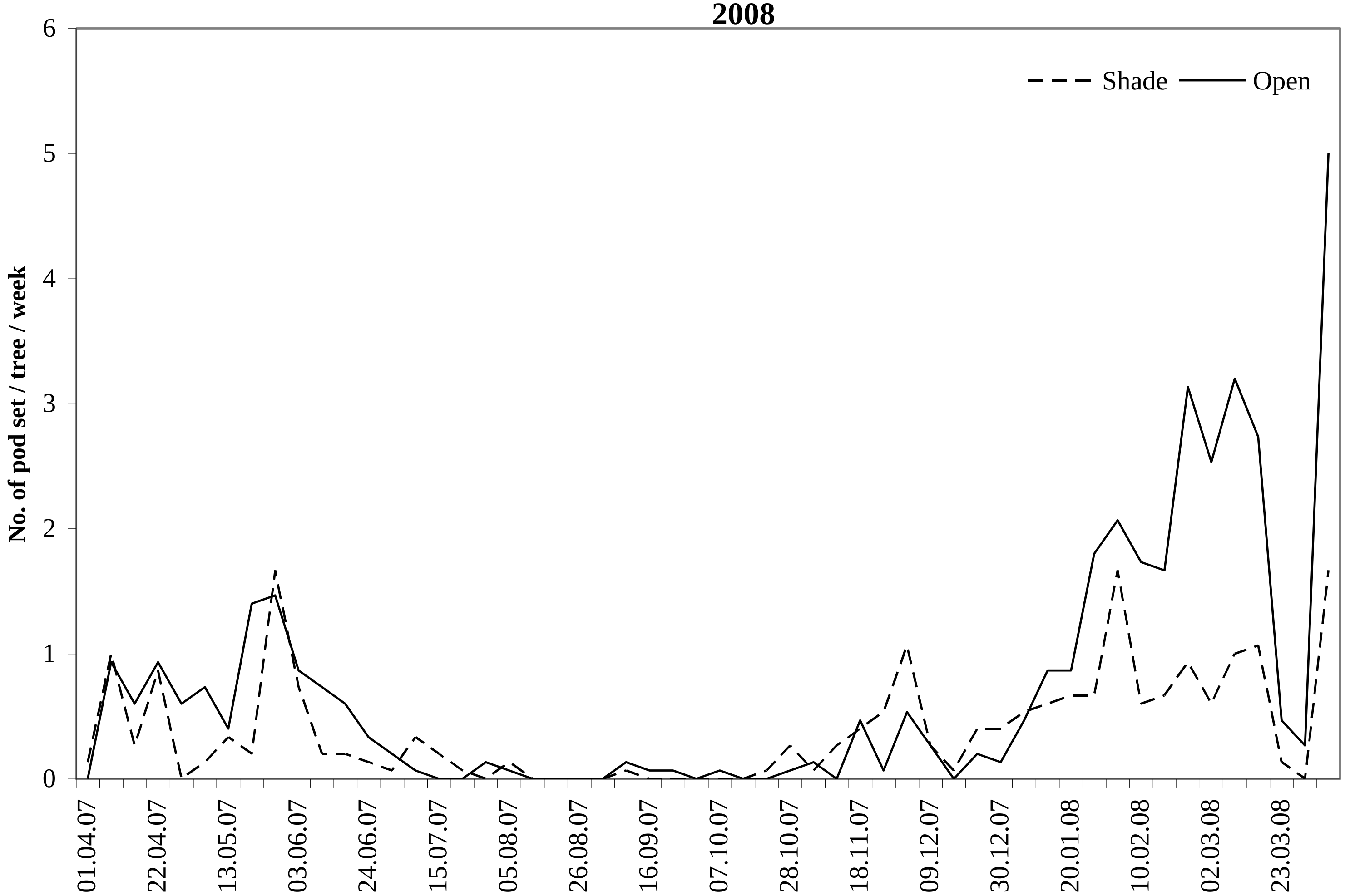


Figure.13 Weekly mean number of pod set in open and shade from April 2007-March 2008



Due to multi-collinearity effect, the pod set had significant positive relationship with maximum temperature and bright sunshine while significant negative correlation with morning and afternoon relative humidity, rainfall and rainy days. The correlations between rainfall and pod set indicated that rainfall had negative (-0.450) relationship with pod set as no significant pod set was seen during the heavy rainfall period from June-October. From the above, it is clear that the pod set appears to be very low during the heavy wet spell due to low bright sunshine available to the crop. Because of multi-collinearity effect among the various weather variables, it is a complex phenomena to find out relationship between weather variables and pod set other than rainfall as rainfall influenced the other weather variables under the humid tropics.

The mean annual fruit set was only 3.0% and out of this one fourth reached maturity (Ravindran, 1980). Mossu and Lotode (1977) reported that rain was unfavourable for pollination and led to low pod set. Fruit set was generally more during the dry months from December to June, and very low or absent during July – September. However, there was a close relationship between the heliothermal units (HTU) and pod set behaviour in cocoa and significant at 0.01 level. It indicates that the pod set of cocoa responds not only to rainfall and its distribution but also to the availability of helio-thermal units. It can be stated that the positive relationship of pod set with maximum temperature was only due to pattern of cherelle production but not due to high maximum temperature that prevailed during the summer.

5.3. Cherelle:

Cocoa produced cherelle round-the-year though weekly variations were significant and almost no cherelles were recorded in August. In the present investigation, the period of cherelle production was found from November to May. The peak cherelle production was seen during summer (February-May) while less from June to October. It revealed that the cherelle production commences by the end of October while ceases with commencement of heavy rain by the middle of June, indicating that the pattern of cherelle production follows the pattern of rainfall. It is one of the reasons, why, the pattern of cherelle production in cocoa was similar irrespective of shade and open.

However, the number of cherelles produced was more under relatively open conditions (Fig.14).

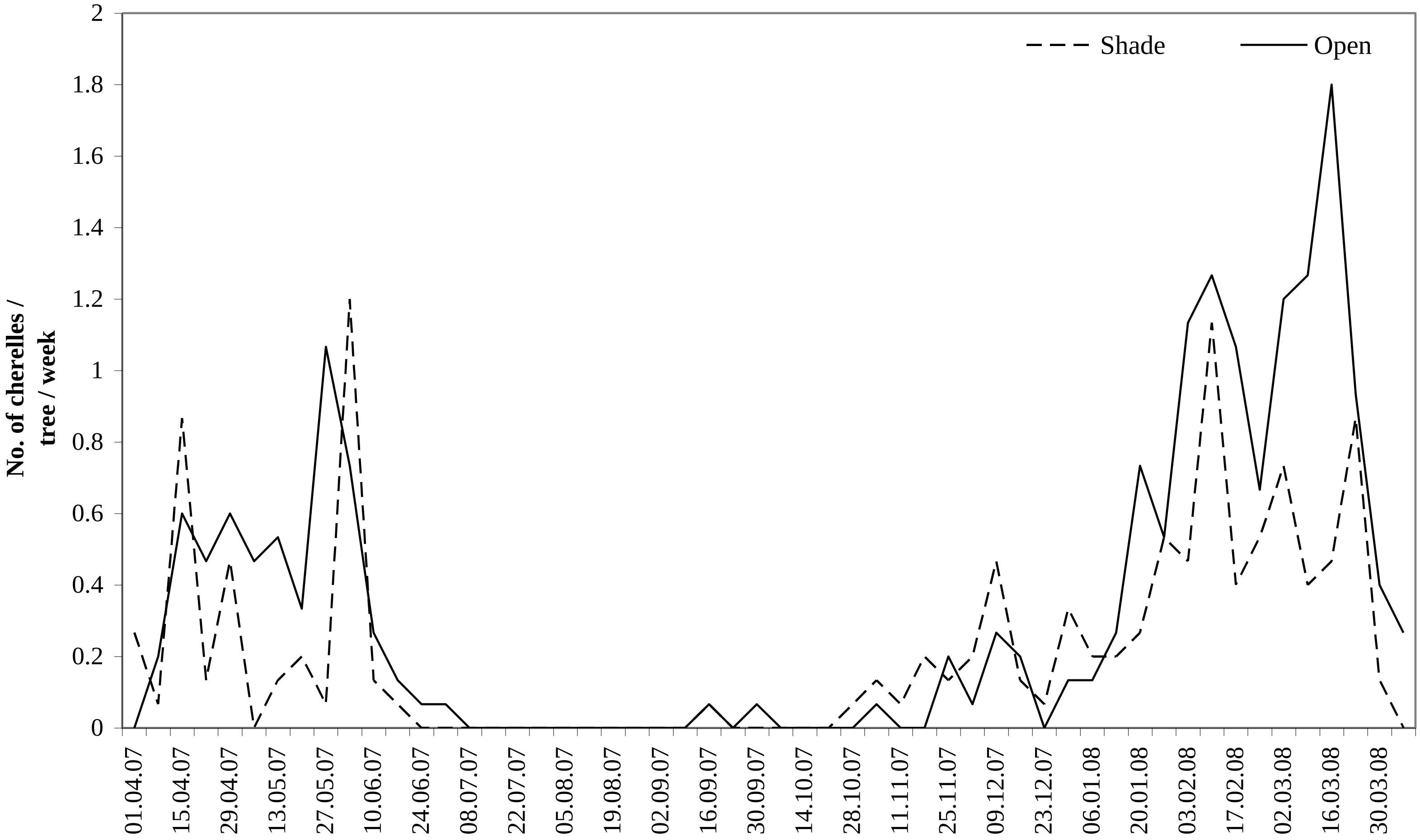
Due to multi-collinearity effect, the cherelle production had significant positive relationship with maximum temperature and bright sunshine while significant negative correlation with morning and afternoon relative humidity, rainfall and rainy days. The correlations between rainfall and cherelle production indicated that rainfall had negative (-0.516) relationship with cherelle production as no significant pod set was seen during the heavy rainfall period from June-October. From the above, it is clear that the cherelle production appears to be very low during the heavy wet spell due to low bright sunshine available to the crop. Because of multi-collinearity effect among the various weather variables, it is a complex phenomena to find out relationship between weather variables and cherelle production other than rainfall as rainfall influenced the other weather variables under the humid tropics.

Describing flowering and fruit setting patterns of cocoa trees at three localities in Costa Rica, Young (1984) reported a marked decline in flowering and cherelle near the end of the rainy season when rainfall was very high. However, there was a close relationship between the heliothermal units (HTU) and cherelle production behaviour in cocoa and significant at 0.01 level. It indicates that the cherelle production behaviour of cocoa responds not only to rainfall and its distribution but also to the availability of helio-thermal units. The farmers from Ivory Coast's cocoa growing zone reported that the cocoa needs lot of sunshine for flowers and cherelles (COPAL Cocoa, 2007). It can be stated that the positive relationship of cherelle production in cocoa with maximum temperature was only due to cherelle production pattern of cocoa but not due to high maximum temperature that prevailed during the summer.

5.4. Pods:

The number of pods harvested was more in October and November, followed by summer (February-April). The peak harvest was seen during April, followed by November in open. Such a trend may not prevail if we take mean monthly yield of cocoa based on the past several year data as the peak yield months in individual years' may be nullified to some extent. The yield pattern of 2007 was similar to that of 2004. It could be

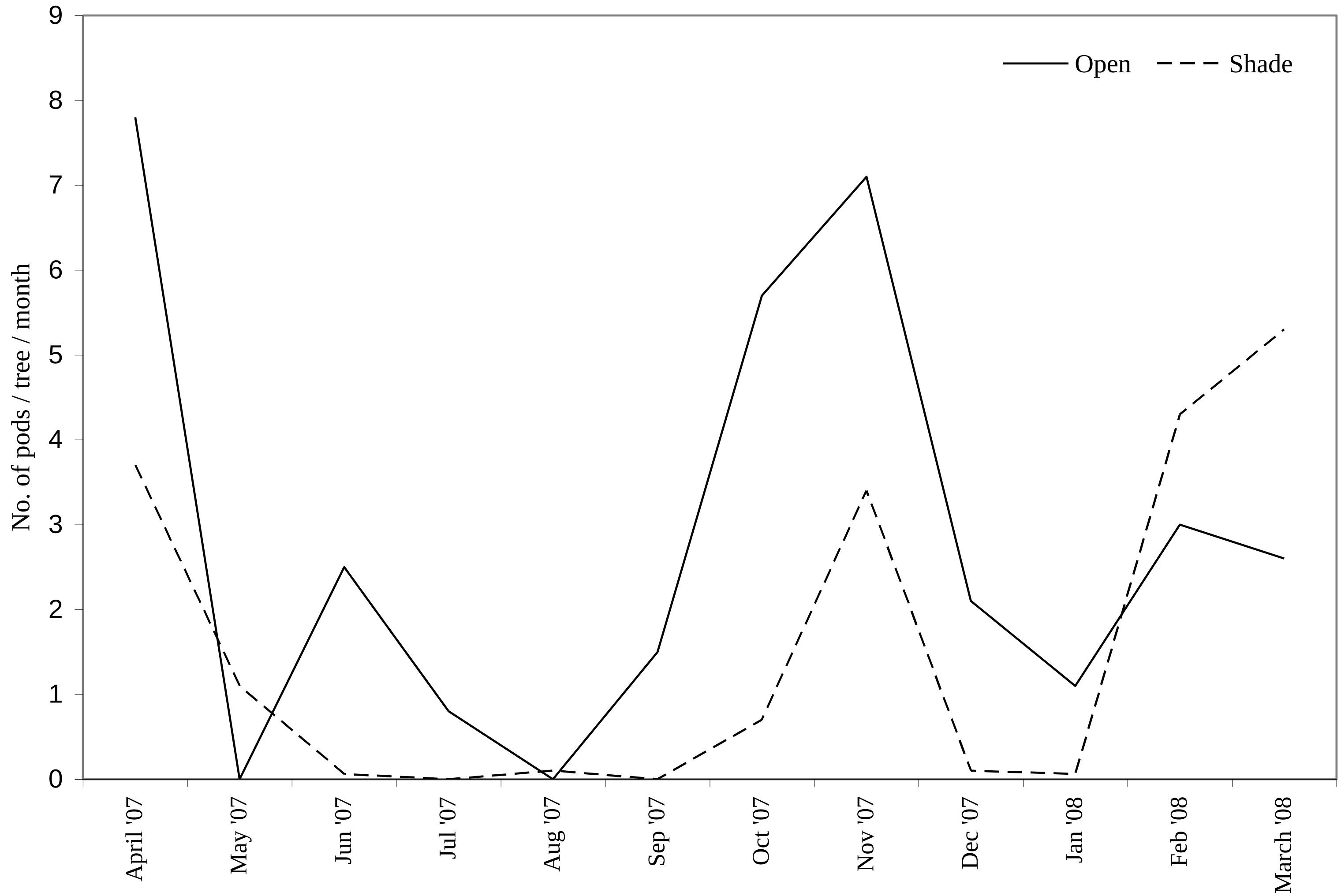
Figure.14 Weekly number of cherelles in open and shade from April 2007 to March 2008



attributed to the variation in weather variables. The pattern of pod harvest was different between the habitats (open and shade) as the peak harvest in shade appeared during February – March while October – November in open (Fig. 15). The number of pods harvested was also more under open conditions when compared to that of shade. Overall, the pods harvested during the post monsoon season (October-November) were high. It was attributed to more number of pods set during summer season before the commencement of monsoon. The low yield during December-January is because of the low fruit set during June-July. March-April period had high yield because of the more fruit set during October-November. One of the factors for low yield obtained during 2007 was due to the low fruit set during the prolonged rainy season unlike in other years. The yield during monsoon season was low because of soil moisture stress from January to March and high summer temperature prevailed during summer.

In countries with marked wet and dry season, the main harvest occurred five to six months after the start of wet season, as reported by Bridgeland (1953) and Alvim (1967). Purseglove (1974) observed that the cocoa plants produced pods throughout the year, but the main harvest usually began at the end of the wet season and continued for a period of three months. In West Africa, where a long dry season exists between October – November to March – April, about 80-90% of the crop was harvested in a relatively short period between September and December. Wood (1985) also showed that there were one or two peak harvest periods and there was some cocoa to be harvested at all times of the year. He also reported that in Ghana, on an average, 25% of the crop was harvested in the peak month, November, which was about six months after wet season began. The studies conducted by Prameela (1997) inferred that the high yield during April-May is due to the profuse flowering in November-September. The present study is in confirmation with the above studies, except under shade where the yield pattern was different. However, such studies are to be carried for more number of years (at least for five years) to draw conclusions. More information in this direction is provided in succeeding section on"Climateandcocoa".

Figure.15 Mean number of pods harvested in open and shade from April 2007-March 2008



5.5. Pod and bean characters:

The pod harvested during the month of November (post monsoon) was superior in all the characters when compared to the pods in February and March. The pods harvested during March recorded 44 per cent reduction in pod weight and 29 per cent in bean weight, while it was 7 and 9 per cent in February. The pods harvested during September and February had intermediary size. The pod and bean weights were high during the post monsoon season followed by rainy season. It is obvious that less number of pods during the rainy season are likely lead to more pod and bean weights. At the same time, better pod and bean weights during post monsoon season could be attributed to favorable environmental conditions like moderate temperature and better soil moisture availability. The study reveals that the low pod and bean weights during summer were due to high number of pods produced, moderate to severe soil moisture stress and high maximum temperature including temperature range. In contrast, no soil moisture stress and less number of pods during the rainy season led to better pod and bean weights during the rainy season. Interestingly, the number of pods harvested, bean weight and other related characters were superior during the post monsoon season. The superiority of pod and bean qualities established during post monsoon could be attributed to favourable weather conditions like moderate temperature and better soil moisture availability.

Egbe and Owolabi (1972) found lowest bean weight, lowest butter fat and highest shell percentage for the February – May crop in Nigeria and highest bean weight, highest butter fat and lowest shell percentage for the October – January crop. The pods harvested from September to December will have the maximum size and this size get reduced by 4 % in January, 8.2 % in February, 28 % in March, 38 % in April and 40 % in May (CCRP, 2004). The present study is in confirmation with the above studies.

5.6. Climate and cocoa over Kerala

The state of Kerala is one of the cocoa plantation states and ranked first in cocoa production in India. In 1980s, the area under cocoa was very high and revolved around 18,000 ha. Thereafter, a sharp decline was noticed and reached to its low (6900ha) in 1994-95 indicating a decline of 62 per cent in area. A gradual regain in cocoa area was noticed since 1995-96 onwards and stabilized at 10,500ha in 2007-08. Overall there was a sharp decline of 42% in area during the study period. The cocoa production was the lowest (1500t) in 1982-83 and the least productivity (82kg/ha) was recorded during the year followed by 215kg/ha in 1983-84. As a whole, the study revealed that there was a sharp decline in cocoa area while increase in production and productivity.

The low production of cocoa during the introduction of crop could be attributed to the lack of technologies and management. In addition, the cocoa had experienced the market crisis during early 1970s, 1980s and 1990s during which most of the cocoa plantations were cut and removed. High inter-annual variation in cocoa production could be attributed to weather aberrations as no alternate bearing tendency is noticed. High rainfall adversely affected the annual cocoa production of the State. It could be attributed to waterlogging or sometimes to floods in cocoa plantations during the heavy monsoon rainfall period from June-September. Hassan *et al*. (1981) observed a significant negative correlation between the number of harvested pods and number of rainy days. He also stated that heavy rainfall is detrimental to cocoa pod production. This was also reported by Prameela (1996). For example, rainfall recorded during 1994-95 was high (3183mm) in which annual cocoa production was low (4300t) while it was low (2481mm) during 1985 and the production was high (6100t). In the case of surface air temperature, the mean temperature had influenced the annual yield negatively. For example, the mean annual temperature was high (28.2°C) and the cocoa production was recorded as 5900t during 1987. In contrast, the surface air temperature was low (27.7°C) during 1996 and cocoa production was recorded as 5800t. During high maximum annual temperature, the summer temperature (February-March) was of the order of 37-39°C though it didn't reflect on actual annual temperature as the annual temperature is the mean of twelve months. It revealed that high maximum temperature during summer may be detrimental to cocoa production.

5.7. Climate and cocoa over Vellanikkara

The annual number of pods was low (28.2 pods/tree) during 2004, 1998 (40.4 pods/tree), 2002 (41.1 pods/tree), 2006 (41.1 pods/tree), 2003 (41.7 pods/tree) and 1995 (42.7 pods/plant) while more during 1993 (72.2 pods/tree), 1992 (68.2 pods/ tree), 1996 (66.1 pods/tree) and 1999 (59.6 pods/tree). The mean peak harvest was noticed during

May (6.1 pods/tree), followed by March (5.2 pods/tree) while less in February (2.7/tree). The coefficient of variation was very high (48.9-124.3 %) in monthly pod yield of cocoa while less in the case of seasonal (33.0-72.2 %) and annual yield of cocoa (21.7 %). The cocoa yield is also highly variable during the rainy season (June-August) as the coefficient of variation is very high, varying between 88.6 and 124.3 per cent. The mean seasonal pod yield was more during the summer (4.7 pods/tree), followed by post monsoon season (4.2 pods/tree). The number of pods harvested was low (3.7 pods/tree) during winter.

The daily maximum temperature during the period from January to May, daily rainfall from December to May and rainfall in the monsoon season during the low and high yielding years were critically analysed to find out the possible explanation in variation of pod yield of cocoa. The maximum temperature during summer showed that there was a sharp rise (1-3°C) in maximum temperature during the period from 14th January to 16th March in 2004 (the worst drought year) as against the normal maximum temperature of 33.0-36.5°C (Fig.16). The drought during summer led to a severe water deficit which was prevalent till May. Almost all the surface water resources dried up due to failure of northeast monsoon across the State of Kerala during 2003-04. In addition, lack of summer showers during February and March worsened the situation and led to early severe drought, which was identical to late summer drought of 1982-83. It adversely affected the plantation crops' production. Black pepper vines wilted and dried up. Heavy loss was noticed in black pepper gardens. The yield loss was more than 30 % in cardamom tracts of Idukki District due to severe moisture stress coupled with adverse weather during the period. Similar trend was also noticed in the case of cocoa, as the reduction of pod yield was to the tune of 43 per cent in 2004. A decline of 39 per cent in annual cocoa yield was noticed when large field sample size was considered with in the same farm (Amma *et al*., 2006) Similarly, the maximum temperature was high in all the low yield years like 1995 (42.7 pods/tree), 1998 (40.4 pods/tree), 2002 (41.1 pods/tree) and 2003 (41.7 pods/tree) when compared to that of annual yield (49.6 pods/tree). The yield reduction during the above years against mean pod yield was 14, 19, 18, and 16 per cent, respectively. The annual maximum temperature was the highest (33.0°C) during 1995 and it was always high against the normal during summer months except in May (Fig.17) in which the cocoa yield was low as mentioned above. Though the annual

Figure.16 Actual and normal maximum temperature from January-May 2004

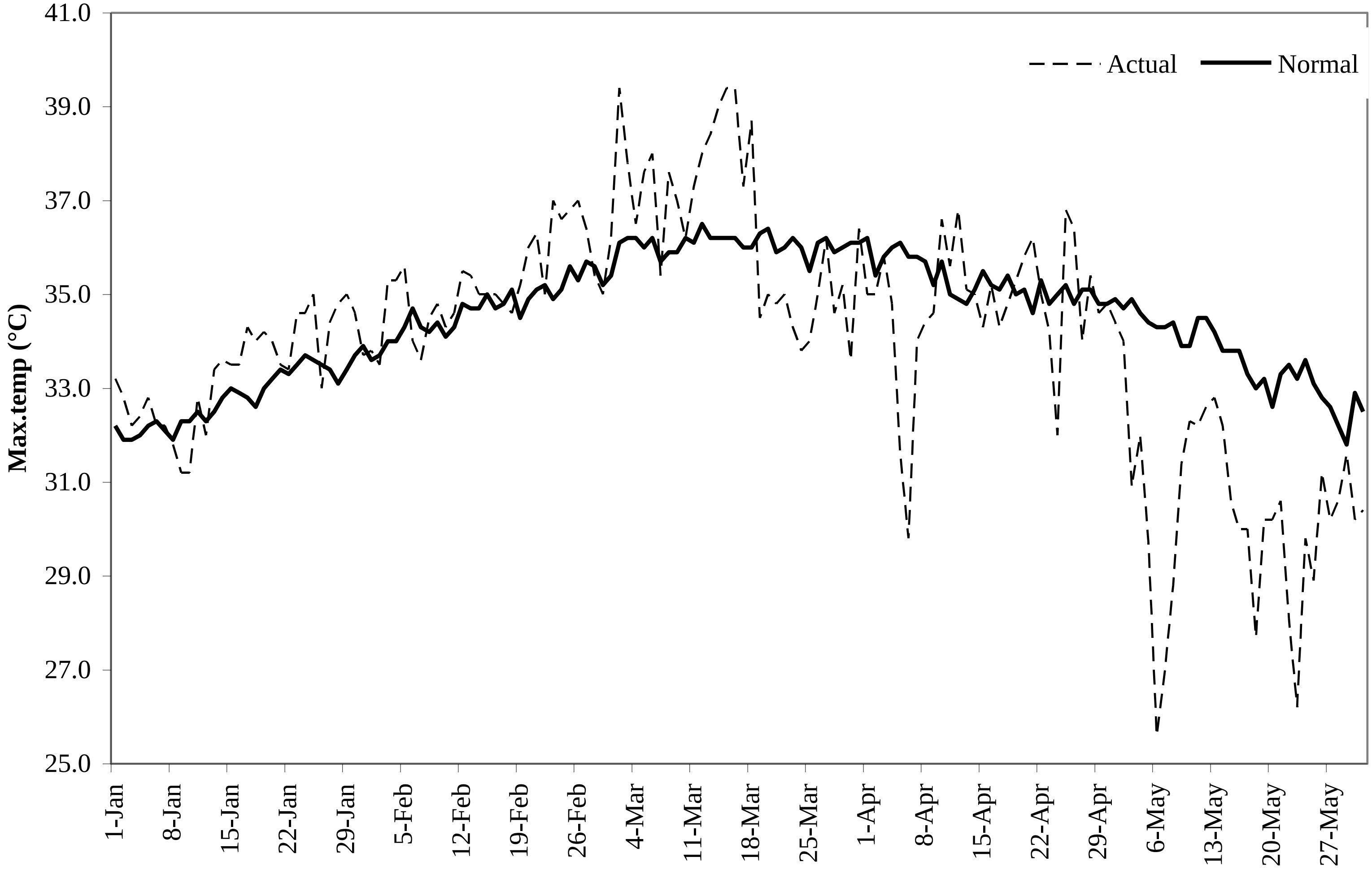
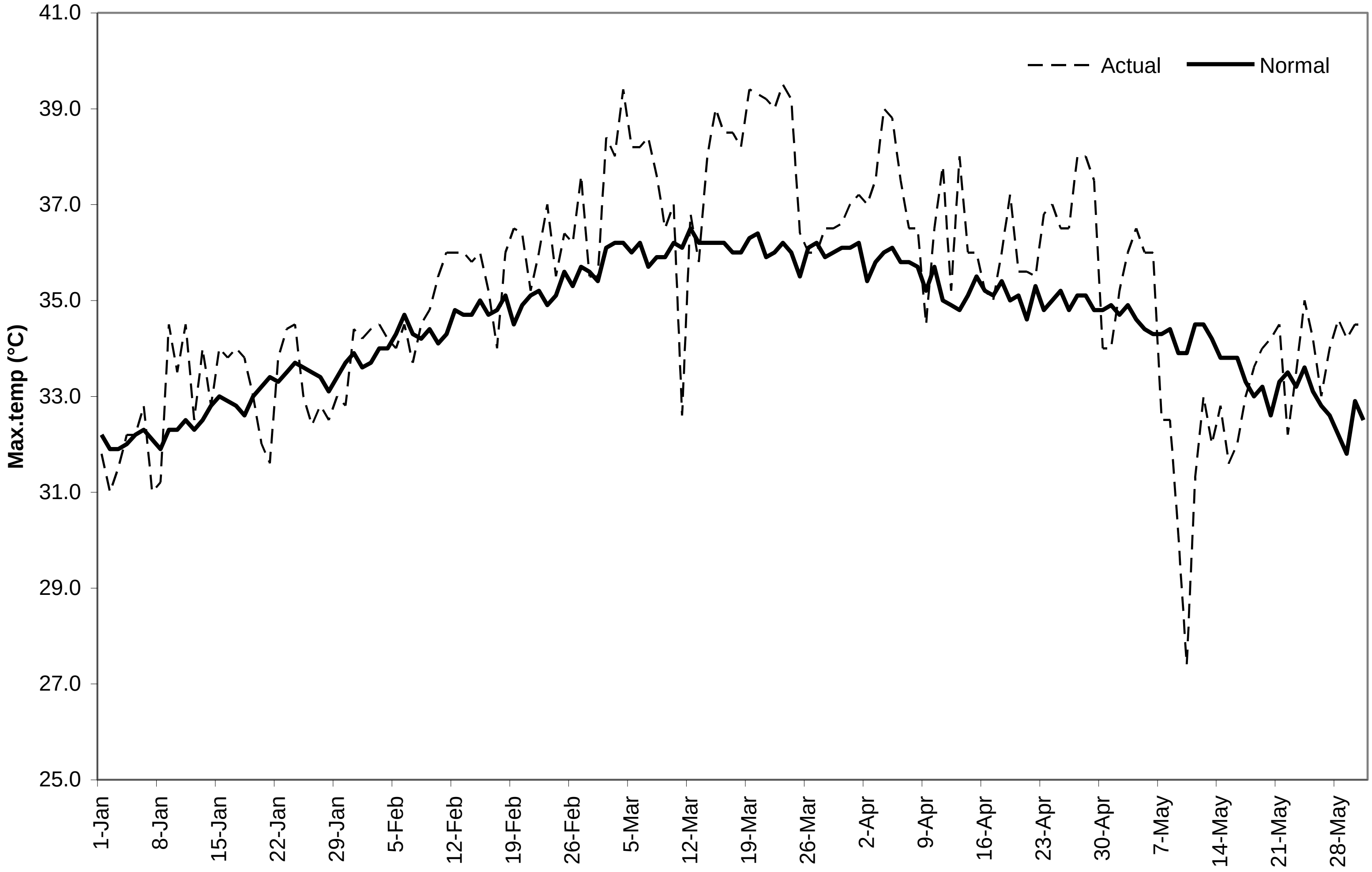


Figure.17 Actual and normal maximum temperature from January-May during 1995



maximum temperature was 33°C, the summer temperature went up to 37.6°C during March. Murray (1972) reported that the apical dominance was lost when cocoa is constantly exposed to high temperature. In the good yield years like 1993, the maximum temperature from January to March was below normal (1-4°C) and the yield obtained was 33 per cent more than the normal (Fig.18). High yield during 1993, 1996 and 1999 could be explained due to low maximum temperature during summer, followed by relatively less rainfall during monsoon. Similar trend was noticed to some extent in 1992 also, during which high yield was obtained. However, the maximum temperature recorded in March and April during 1992 was relatively high while less in January and February against the normal (Fig.19). Interestingly, abnormal wet spells were not noticed during the peak rainy season from June to September and rainfall recorded was relatively low with intermittent dry spells against normal (2122.2 mm) in all the good yield years except in 1992 during which the monsoon rainfall was relatively high (2721.3 mm). Prameela (1997) also reported that heavy rainfall was detrimental to the cocoa pod production. It appears that the maximum temperature from January to March had profound negative influence on cocoa yield during the following months from June to August in addition to high rainfall recorded during the rainy season (Fig. 20). Probably, it might be the only factor which influenced significantly the monthly yield during the rainy season as the yield difference was mainly noticed during the rainy season only between the good and bad yield years (Fig. 21). For example, in 1993 (good yield year) and in 2004 (poor yield year), the difference in yield was noticed only during the southwest monsoon. Similar trends were noticed in all good and bad yield years. According to Alvim (1981), yield variability from year to year was more affected by rainfall distribution than any other climatic factor. In 2007, during the experimental year, the monthly yield pattern during the rainy season was no way different and it was very low from June to August. At the same time, the maximum temperature during the summer was continuously low (34.1°C) against the normal (34.6 °C) except on few occasions (Fig.22). The low maximum temperature during summer, 2007 was explained to summer showers (302 mm) spread in 14 rainy days between April and May. It might have helped in getting better yield other than rainy season as it is categorised under the intermediary yield group. On further examination through step wise regression, it was understood that the model explained43

Figure.18 Actual and normal maximum temperature from January to May 1993

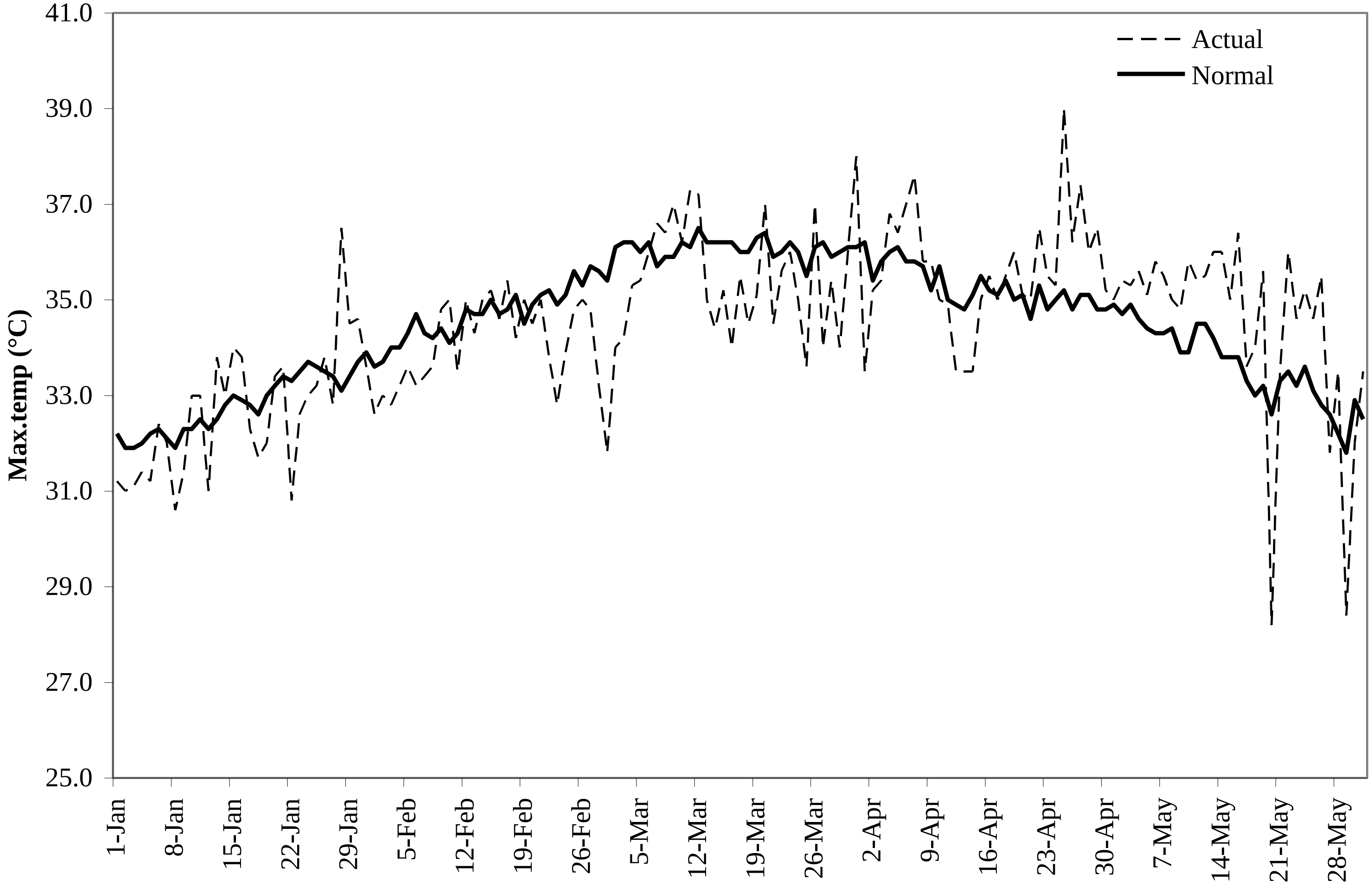


Figure.19 Actual and normal maximum temperature from January-May during 1992

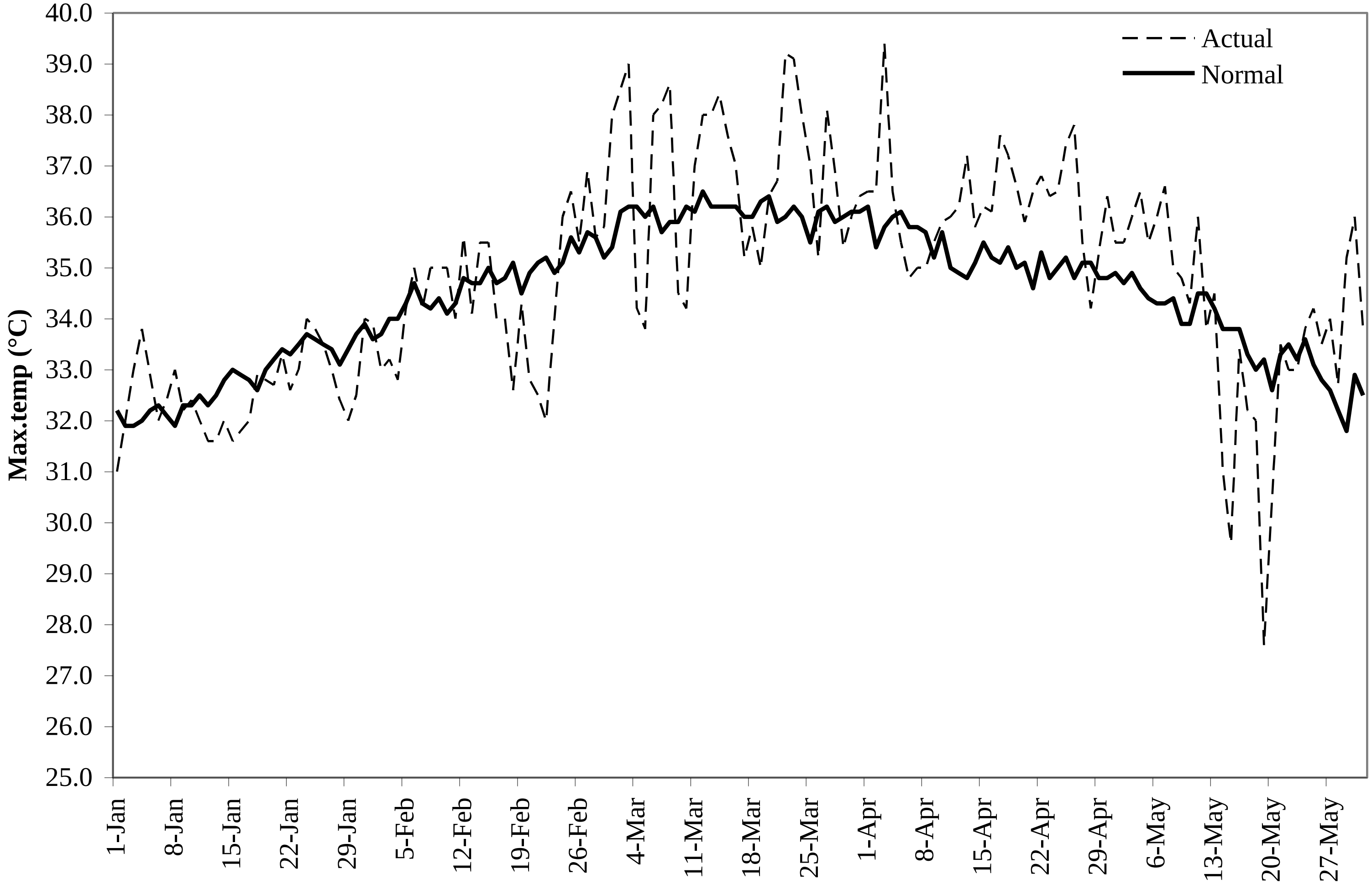


Figure.20. Rainfall during southwest monsoon and cocoa pod yield from 1991-2007 at Vellanikkara

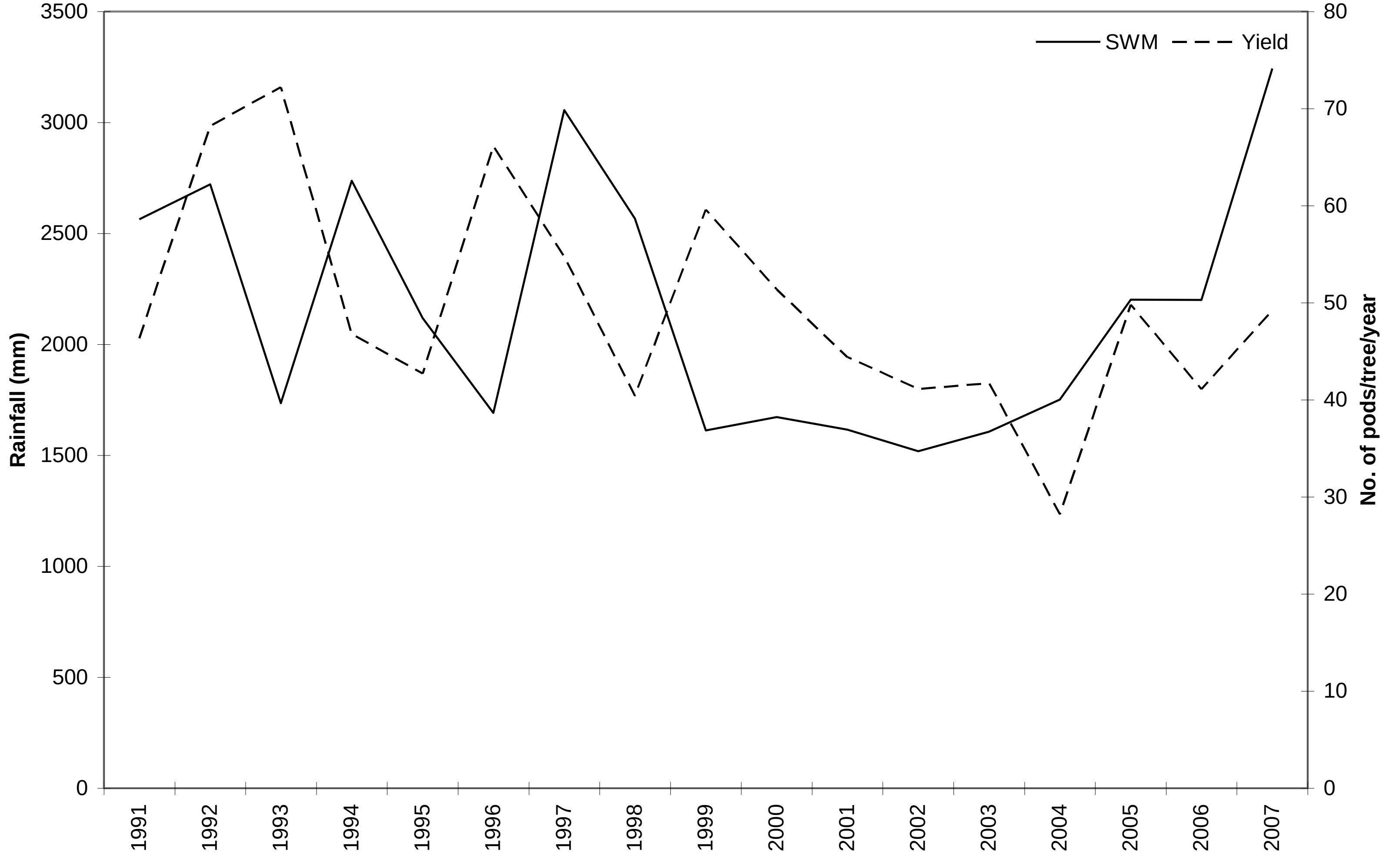


Figure.21. Cocoa pod yield from January to December of a good and bad yield year

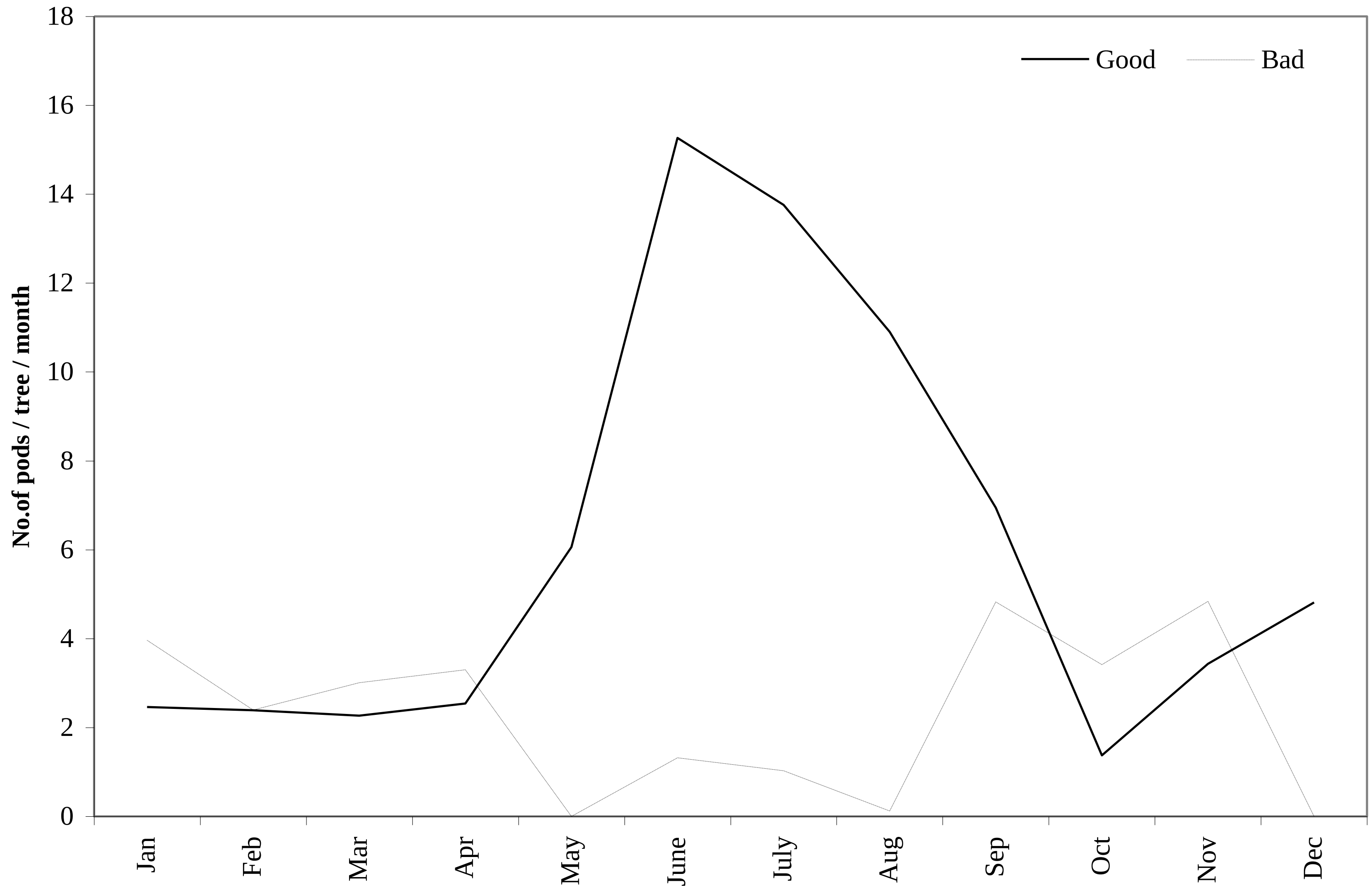
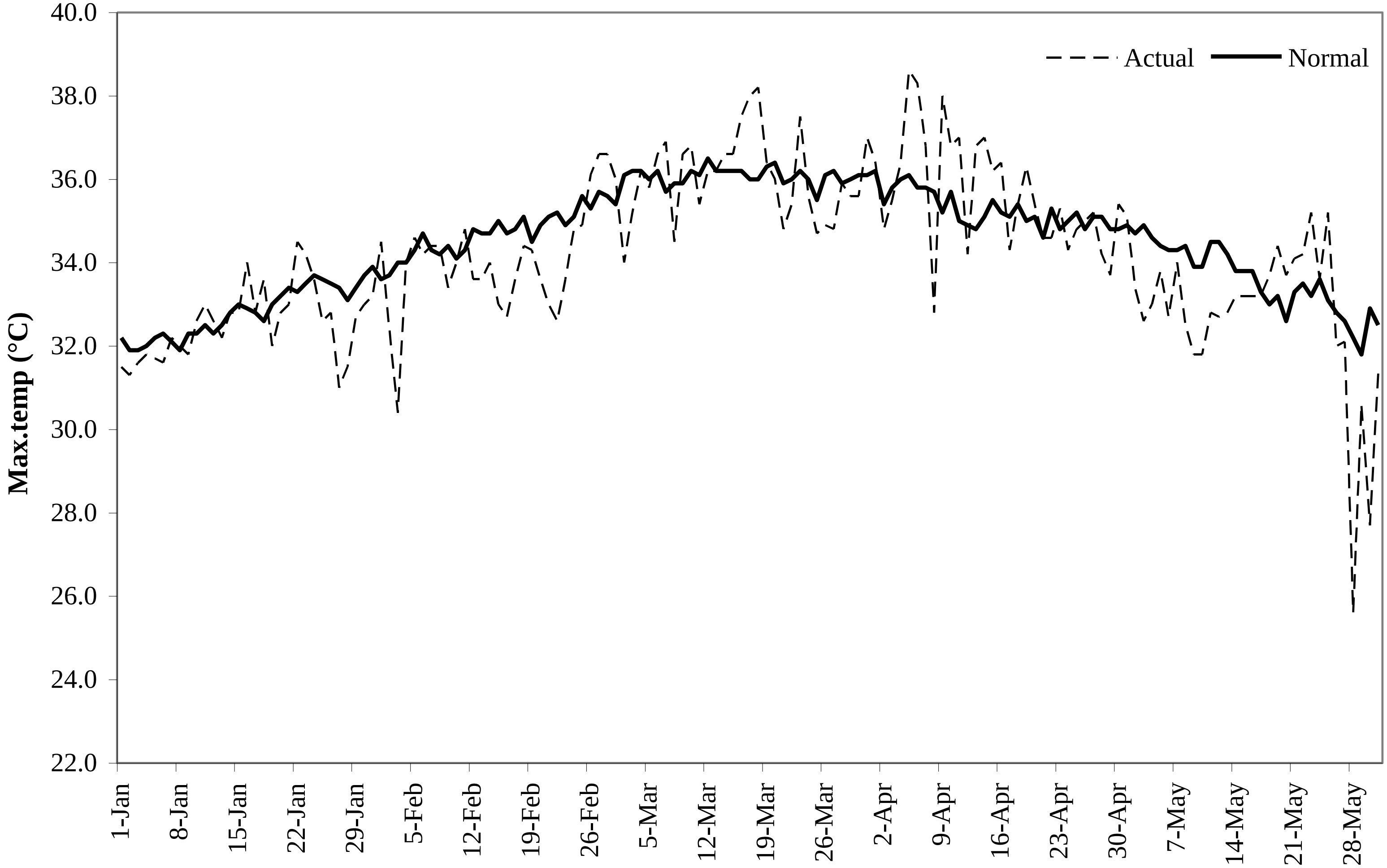


Figure.22. Actual and normal maximum temperature from January-May during 2007



per cent variation in pod yield of cocoa due to maximum temperature. The equation for the yield prediction is as follows;

$$Y= -24.453 + (0.378\ mx1) + (0.516\ mx2);\ (R^2 = 0.43)$$

Y- Yield

mx1 & mx2 - Maximum temperature one and two months before pod production

According to Manurung *et al*., (1988) the climatic components alone were not considered sufficient for predicting the yield potential of bulk cocoa. From the above, it can be inferred that high maximum temperature from January to middle of March together with high rainfall during the rainy season appeared to be detrimental for obtaining better yield in cocoa. Probably, it is one of the reasons why, the cocoa productivity is low across the State of Kerala as the cocoa plantations are exposed to heavy rainfall from June-September and high summer maximum temperature in addition to poor soil moisture under rainfed conditions. Heavy rainfall and continuous wet spell lead to waterlogging with heavy soil moisture. These conditions may lead to lack of soil aeration in cocoa root zone during the rainy season. It appears to be detrimental and lead to immature fruit drop.

Summary

6. SUMMARY

The present investigation on "Crop-weather relationships of cocoa (*Theobroma cacao* L.)" was undertaken at the Department of Agricultural Meteorology, College of Horticulture, Vellanikkara. The trees were selected from Cadbury - KAU Co-operative Cocoa Research Project farm, Vellanikkara. Thirty trees were selected, in which 15 were grown under shade (rubber) and 15 were under open conditions. The selected trees were classified into different yield groups. The plants grown in shade were classified as plants giving yield of <15, 15-30 and more than 30 pods per tree per year. In the same way, plants in open were classified as plants giving yield of <60, 60-90 and more than 90 pods per tree per year. In each yield category, five plants were selected and marked for the weekly observation. The biotic events such as flowering, pod set, cherelle and final yield were recorded weekly from April 2007 to March 2008. The salient results of the study were summarised and presented in this chapter.

The biotic events (flowering, pod set and cherelle production) in cocoa were seen throughout the year though weekly variations were significant and almost no biotic events were recorded in August. The flowering in cocoa was initiated in November after the rainy period and thereafter an increasing trend was seen in number of flowers. The flower production significantly increased from January and attained a peak in May which contributed 26.9 per cent to the total annual flower production. There was a sudden decline in flower production during the rainy months (June, July, August, September and October) and insignificant when compared to other seasons. Similar trend was also noticed in the case of cherelle production and pod set.

The pattern of biotic events in cocoa under open and shade were also similar. However, the average number of flowers, pod set and cherelle was always higher in the open conditions when compared to the cocoa grown under shade conditions. The intensity of light availability varied from 10996 (September) to 22103 lux (May) in cocoa under the shade while it was 27293 (April) to 45177 lux (May) in open. It is observed that the light availability on an average over cocoa under rubber (shade) was only 45 per cent, varying from 39 % (October) to 56 % (April). All the biotic events produced in cocoa, including yield is relatively high in open conditions when compared to that of shade due to better availability of light to the crop under open conditions.

The overall percentage contribution of number of flowers, pod set, and cherelles produced during summer was high (59.1) when compared to that of the other seasons. It was only 7.3 per cent in rainy season (June-September) and 7.2 per cent during post monsoon season (October-November) while 26.4 per cent in winter (Dec-Jan). All the yield groups showed similar trend in flowering, pod set and cherelle production of cocoa. It was also similar in the open as well as shade. However, the percentage contribution varied depending upon the yield group though it was high in summer irrespective of the yield group.

The present study supports the view that the variations in flowering period across the Northern Hemisphere can be attributed to distribution of rainfall, temperature and the day length as it varied from one location to another within the season during summer (March-September). If that is the case, Hopkins bioclimatic law (1938) holds good in time of flowering in different countries across the Northern Hemisphere. It can be stated as “A biotic event in North America will, in general, show a lag of four days for each degree of latitude, five degree of longitude and 400 feet of altitude, northward, eastward and upward in spring and early summer”.

The number of pods harvested was more in October and November, followed by summer (February-April). The peak harvest was seen during April, followed by November in open. The pattern of pod harvest was different between the habitats (open and shade) as the peak harvest in shade appeared during February – March while October – November in open. However, it can be confirmed if studies are conducted further for more number of years.

The pods harvested during November (post monsoon season) was superior in pod weight (562g), pod length (17.03 cm) and bean weight (1.28). The pods harvested during September (rainy season) and January (winter) showed intermediary, having the pod weight of 555 g/pod in September and 524 g/pod in January. The pods harvested during summer recorded 44 and 29 per cent less in pod weight and bean weight, respectively when compared to post monsoon season. Hence, a harvest of five pods during the post and southwest monsoon seasons equals to nine pods harvested during summer season, 5.4 pods during winter while 5.1 pods in south west monsoon. Though the number of pods harvested during summer is high, the yield recorded in terms of pod weight was high during the post monsoon season.

The multicollineartity effect among different weather variables indicated that rainfall had significant negative correlation with bright sunshine, maximum temperature while positive correlation with morning and afternoon relative humidity, and number of rainy days. Bright sunshine also had strong negative relationship with rainfall, number of rainy days, morning and afternoon relative humidity. Due to multicollineartity among different weather variables, a positive correlation with rainfall may result to negative correlation with maximum temperature and bright sunshine and vice versa.

The flowering appears to be very low during the heavy wet spell due to mechanical damage as well as low bright sunshine available to the crop. Nevertheless, the summer rains (February-May) two weeks before flowering influenced the flowering favourably. In the absence of rains from November to May, the maximum temperature revolves around 35 to 37°C during summer (February-May) while 28-30°C during the rainy months. It is one of the reasons, why, the flowering had positive correlation with maximum temperature when it had negative correlation with rainfall. It can be stated that the positive relationship of cocoa flowering with maximum temperature was only due to flowering pattern of cocoa but not due to high maximum temperature that prevailed during the summer.

There was a positive trend between the helio-thermal units (HTU) and biotic events such as flowering, pod set and cherelle production in cocoa and significant at 0.01 level. It indicates that the flowering, pod set and cherelle production behaviour of cocoa responds not only to rainfall and its distribution but also to the availability of helio-thermal units.

The coefficient of variation was very high (48.9-124.3 %) in monthly pod yield of cocoa while it was less (23 %) in the case of annual yield of cocoa. It indicated that the monthly cocoa yield is very sensitive to extreme weather conditions unlike in the case of annual yield. The cocoa yield is also highly variable during the rainy season (June-August) as the coefficient of variation is very high, varying between 88.6 and 124.3 per cent. Cocoa is a regular yielder with no biennial bearing tendency. It reveals that the monthly, seasonal and inter-annual variation of cocoa yield could be attributed to weather aberrations.

The State of Kerala is one of the cocoa plantation states and ranked first in India. In 1980s the area under cocoa was very high and revolved around 18,000 ha. Thereafter, a sharp decline was noticed and reached to its low in 1994-95. The cocoa had experienced the market crisis in early 1970s, 1980s and 1990s during which most of the cocoa plantations were cut and removed. The percentage decline in area was 62 per cent. A gradual regain in cocoa area was noticed since 1995-96 onwards and stabilized at 10,500ha in 2007-08. Overall there was sharp decline (42%) in area during the study period. The production and productivity was the lowest in 1982-83 (82kg/ha) followed by1983-84 (215kg/ha). The maximum (6000t) cocoa production was recorded in 2007-08 with lesser area. The trend was similar in the case of productivity, recording the maximum in recent years (570kg/ha). As a whole, the study revealed that there was a sharp decline in cocoa area while increase in production and productivity.

The maximum temperature from January to March had a profound influence on annual cocoa yield. Whenever there was an increase in maximum temperature, the annual cocoa yield recorded was low. The relationship between growing degree days (GDD) and yield also indicated similar trend as in the case of maximum temperature. The maximum temperature during summer was high (34.7^{o}C) in poor yield years while less (34.2^{o}C) in good yield years. A mean maximum difference of 1.1^{o}C was noticed in April between good and poor yield years. The maximum temperature during summer showed that there was a sharp rise (1-3^{o}C) in maximum temperature during the period from 14th January to 16th March in 2004 (the worst drought year) as against the normal maximum temperature of 33.0-36.5°C. This was noticed in all bad yield years. The reduction of pod yield was to the tune of 43 per cent in 2004.

There was an inverse trend between the annual rainfall and cocoa yield. Whenever the annual rainfall was very high, the annual cocoa yield was low. The relationship between mean annual soil moisture and yield also indicated similar trend as in the case of rainfall. It was found that the difference in cocoa yield during rainy months was very significant followed by post monsoon when compared to that of other seasons. On an average, the decline in yield was 45 per cent in bad yield years when compared to the mean yield while 45 per cent increase in good yield years during the southwest monsoon. The percentage increase in yield during good years when compared to that of bad years was 72 and 58 per cent during southwest monsoon and post monsoon, respectively.

A decline in annual rainfall at the rate of 6.9 mm/year was noticed during the study period from 1991-2007 at Vellanikkara. Similar trend was noticed in southwest monsoon (11.4 mm/year) and post monsoon season (11.2 mm/year). In winter, no declining trend in rainfall was noticed. In contrast, a sharp increase (20.3 mm/year) was noticed in summer rainfall. In the case of surface air temperature, the maximum temperature was declining (0.03°C/year) during the study period (1991-2007) while increase in night temperature (0.005°C/year).

There was an increase (15mm/year) in annual rainfall over Kerala during the study period from 1982-2007. A cyclic trend in seasonal rainfall was noticed as the monsoon rainfall was declining (4.7mm/year) while increasing (10.2mm/year) in post monsoon rainfall. Similarly, winter rainfall was declining (1.0mm/year) while increasing in summer rainfall (10.1mm/year).

On examination through step wise regression, it was understood that the model explained 43 per cent variation in pod yield of cocoa due to maximum temperature alone. It revealed that high maximum temperature during summer with heavy rainfall during rainy season is likely to affect the annual cocoa yield adversely.

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Appendices

Appendix.1. Weekly mean weather variables at Vellanikkara from April 2007 to March 2008

Date	Max.temp (°C)	Min. temp (°C)	RH I (%)	RH II (%)	BSS (hrs)	Rainfall (mm)	Rainy days
01.04.07	35.5	25.0	86	47	7.3	0	0
08.04.07	36.6	25.6	86	45	7.5	0.8	0
15.04.07	36.0	25.2	84	55	5.7	0	0
22.04.07	35.5	24.2	82	47	9.1	28.6	1
29.04.07	34.7	24.6	86	56	8.4	23.6	1
06.05.07	33.8	24.9	88	59	6.9	63.9	3
13.05.07	32.6	24.7	88	64	6.2	15.6	2
20.05.07	33.3	24.9	83	56	9.6	0.3	0
27.05.07	34.0	25.1	85	65	6.6	19.6	1
03.06.07	30.4	23.4	91	72	5.0	141.1	4
10.06.07	32.1	24.5	89	68	7.4	77.6	3
17.06.07	29.3	23.3	93	78	1.7	231.9	7
24.06.07	27.3	22.4	94	90	0.1	389.3	7
01.07.07	30.5	23.5	93	71	2.2	127.6	6
08.07.07	28.4	22.7	95	82	0.0	398.8	7
15.07.07	28.8	22.9	94	86	1.1	331.4	7
22.07.07	27.9	23.1	93	82	1.5	298.7	6

29.07.07	28.1	22.7	92	81	0.4	90.1	5
05.08.07	28.3	22.8	92	79	1.0	77.7	7
12.08.07	27.8	22.2	92	85	0.7	329.3	7
19.08.07	30.6	23.4	91	65	6.8	0.6	0
26.08.07	29.6	23.2	91	70	4.8	47.6	3
02.09.07	28.5	22.5	91	78	1.6	109.2	5
09.09.07	29.3	22.4	93	75	1.3	130	5
16.09.07	29.5	23.5	91	78	3.4	208.5	5
23.09.07	28.8	23.2	94	84	1.8	210.6	7
30.09.07	29.9	22.8	93	74	4.0	168.5	5
07.10.07	30.2	22.5	94	66	5.3	86.4	3
14.10.07	31.1	22.7	92	66	5.6	55.4	1
21.10.07	30.6	22.4	91	70	3.3	137.2	5
28.10.07	30.4	22.5	85	70	3.2	76.4	4
04.11.07	29.5	22.3	91	75	3.8	82.1	4
11.11.07	31.5	22.5	91	65	5.4	17.7	1
18.11.07	31.8	19.7	76	43	9.5	0	0
25.11.07	32.1	22.2	74	51	8.7	0	0
02.12.07	32.0	21.2	72	46	9.9	0	0
09.12.07	31.6	23.2	68	44	8.9	0	0

16.12.07	31.3	23.4	68	46	4.6	0	0
23.12.07	30.2	24.5	71	57	3.5	8.7	1
30.12.07	32.8	19.7	84	37	8.4	0	0
06.01.08	32.3	21.1	82	39	9.1	0	0
13.01.08	31.7	22.7	75	39	9.9	0	0
20.01.08	32.4	21.6	69	32	9.9	0	0
27.01.08	32.7	21.3	81	41	9.0	0	0
03.02.08	32.4	21.6	85	50	8.5	0	0
10.02.08	32.6	23.0	83	49	6.1	0	0
17.02.08	33.0	23.6	87	49	7.3	29.7	3
24.02.08	34.9	22.9	73	33	9.8	0	0
02.03.08	34.6	22.7	71	30	9.3	0	0
09.03.08	35.3	22.6	68	24	9.8	0	0
16.03.08	34.5	22.8	70	41	7.0	92	2
23.03.08	30.6	23.9	83	69	2.2	113.3	5
30.03.08	32.1	23.7	89	60	7.8	0	0
07.04.08	32.6	23.8	89	57	8.0	44.1	1

Appendix.2. Availability of light (lux) in open conditions at CCRP farm, Vellanikkara during different months

Time (hrs)	April	May	September	October	November	December	January	February	March
6 00	799	6204	243	286	286	481	307	377	665
7 00	4638	16100	2084	2804	2804	4020	608	3838	3372
8 00	12300	28700	10500	14140	14140	17740	5500	13480	8520
9 00	20580	45440	19980	26540	26540	36020	26060	29340	29700
10 00	42260	59420	43820	60040	60040	57780	53680	50920	49840
11 00	50480	81600	61460	84740	84740	67580	69240	67520	77580
12 00	58140	99460	76340	93580	95180	77460	95500	96700	81320
13 00	65500	107900	59000	100340	99740	99660	98880	99880	102220
14 00	46640	76440	58780	80460	80560	76860	89900	87720	91980
15 00	24720	40220	24320	44100	44100	57220	41500	33860	39700
16 00	16800	17980	3000	24660	24660	27820	37700	31900	34160
17 00	10480	6800	2400	13640	13640	7740	20700	22660	23320
18 00	1480	1040	800	4980	4380	4100	1380	2020	2160

Appendix.3. Availability of light (lux) under rubber at CCRP farm, Vellanikkara during different months

Time (hrs)	April	May	September	October	November	December	January	February	March
6 00	467	710	66	51	105	172	144	242	373
7 00	3330	3220	1208	1682	1990	2556	522	2454	2818
8 00	7500	5600	4180	7980	8460	11240	4400	8360	8380
9 00	13280	15460	9960	12680	14160	17480	9620	11580	11740
10 00	19060	25500	13800	17040	20540	23040	11740	13900	16480
11 00	27800	43920	19280	22340	29940	23840	20780	24360	26100
12 00	38980	62260	35520	39700	41860	36880	38880	39940	40800
13 00	48320	67600	22740	60420	63740	60060	49460	49580	50760
14 00	21940	35060	20740	40780	44360	39800	46100	46060	45000
15 00	17660	16860	11920	20040	23000	20120	26060	10900	15340
16 00	7480	9080	2200	10440	12960	13440	7420	7420	8580
17 00	3160	1760	1020	3020	5300	4000	5720	6400	6780
18 00	600	320	326	730	824	852	668	520	680

Appendix.4. Availability of light (lux) in cocoa grown under open at CCRP farm, Vellanikkara during different months

Time (hrs)	April	May	September	October	November	December	January	February	March
6 00	92	109	14	26	26	58	31	42	54
7 00	1134	574	286	584	584	768	160	484	738
8 00	3454	1020	474	844	844	1174	860	1054	2480
9 00	6752	2480	1254	3180	3180	3840	1760	2700	5420
10 00	10760	4160	1400	3280	3280	4300	2800	4100	8080
11 00	12080	5340	2280	4520	4520	5740	4240	5700	10920
12 00	17900	7220	3160	6200	6200	8000	6260	9400	13460
13 00	18020	10240	3460	6620	6620	10520	5800	12140	14900
14 00	14700	9740	3040	7420	7420	9060	7260	13260	12260
15 00	12100	7540	2300	5660	5660	7300	2760	8220	8520
16 00	7780	7380	1700	3820	3820	5480	1500	4760	6040
17 00	3420	1260	474	2920	2920	3000	1080	2380	2980
18 00	360	580	222	504	504	520	204	340	378

Appendix.5. Availability of light (lux) in cocoa grown under shade at CCRP farm, Vellanikkara during different months

Time (hrs)	April	May	September	October	November	December	January	February	March
6 00	13	17	5	12	12	17	15	10	11
7 00	154	135	91	162	162	237	40	98	132
8 00	400	168	206	394	394	358	226	310	368
9 00	483	256	430	574	574	461	310	388	470
10 00	1020	1134	848	980	980	494	500	530	780
11 00	1066	486	916	1020	1020	604	516	652	912
12 00	2280	552	980	1240	1240	714	726	1020	1460
13 00	2360	626	640	960	960	738	974	1260	1800
14 00	1452	400	426	980	980	586	1018	1240	1266
15 00	810	266	288	826	826	394	416	532	640
16 00	452	190	196	696	696	316	224	366	356
17 00	310	114	124	536	536	142	150	220	260
18 00	38	58	24.8	192	192	62	26.4	60	40

Appendix.6. Weekly number of flowers under different yield group of cocoa grown under open conditions

Date/T.No	<60 pods/tree/year					60-90 pods/tree/year					>90 pods/tree/year				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
01.04.07	10	9	4	4	5	8	2	7	1	8	0	14	0	0	0
08.04.07	3	3	7	0	2	3	0	0	0	3	0	4	0	6	0
15.04.07	10	10	13	0	0	1	0	6	0	0	2	0	3	0	0
22.04.07	7	13	11	0	0	1	0	4	0	2	4	0	4	2	0
29.04.07	30	20	12	5	30	8	8	2	6	21	3	13	11	22	23
06.05.07	63	28	24	6	26	11	18	4	14	40	5	24	19	29	32
13.05.07	66	67	32	0	15	4	11	0	4	33	5	5	6	15	2
20.05.07	41	19	21	31	14	20	16	17	7	25	6	39	19	27	29
27.05.07	10	13	28	0	20	5	6	2	0	7	5	29	4	24	12
03.06.07	4	6	12	0	4	3	4	0	0	7	4	22	0	12	6
10.06.07	3	3	2	2	2	0	0	0	0	2	1	4	2	3	1
17.06.07	2	0	0	0	3	0	2	0	0	2	4	0	0	0	0
24.06.07	1	0	0	0	0	0	0	0	2	2	1	4	0	1	0
01.07.07	7	0	0	2	0	2	3	0	0	0	0	1	3	0	0
08.07.07	0	0	0	0	4	0	0	0	0	0	1	3	0	0	0
15.07.07	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0
22.07.07	0	0	2	0	0	0	0	0	0	3	0	0	0	0	0

29.07.07	0	0	0	0	3	0	0	2	1	3	2	2	0	0	2
05.08.07	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12.08.07	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19.08.07	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26.08.07	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
02.09.07	1	0	0	0	1	0	2	0	0	1	2	0	0	1	0
09.09.07	2	3	0	0	0	0	1	0	0	0	0	1	0	0	0
16.09.07	1	0	1	0	0	1	0	2	0	0	4	0	0	2	3
23.09.07	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30.09.07	2	0	0	0	0	0	0	0	0	0	0	0	0	0	2
07.10.07	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1
14.10.07	2	0	0	0	2	0	0	0	1	1	0	1	0	0	1
21.10.07	1	1	0	0	0	1	2	0	1	0	0	1	2	0	0
28.10.07	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
04.11.07	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11.11.07	6	1	0	0	1	0	0	5	0	0	3	0	0	5	17
18.11.07	2	0	0	0	0	0	2	2	0	0	0	0	0	2	8
25.11.07	0	0	0	0	0	0	0	3	0	0	1	0	0	4	10
02.12.07	0	0	0	0	0	0	0	1	0	1	0	3	0	2	3
09.12.07	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1

16.12.07	0	0	0	0	2	1	1	1	0	3	1	1	0	1	0
23.12.07	0	0	0	0	1	1	0	0	0	0	0	0	0	0	1
30.12.07	2	0	0	0	0	2	4	0	0	0	6	0	0	0	7
06.01.08	0	2	2	0	2	9	6	2	0	3	1	0	0	6	3
13.01.08	9	3	6	3	9	11	9	5	3	14	10	7	4	19	14
20.01.08	14	1	7	1	11	10	7	2	5	12	9	7	4	14	20
27.01.08	4	0	9	0	4	7	3	6	6	19	10	1	1	1	5
03.02.08	8	0	10	3	4	4	3	0	5	11	4	0	3	2	5
10.02.08	12	8	13	8	7	6	9	3	4	7	1	9	4	6	17
17.02.08	34	13	14	12	13	9	12	5	6	13	4	25	8	11	29
24.02.08	40	6	27	5	11	13	7	6	1	11	8	19	8	17	10
02.03.08	19	16	18	5	6	9	6	0	7	13	6	15	21	5	17
09.03.08	7	12	6	3	6	2	3	3	6	7	6	11	12	7	8
16.03.08	10	2	20	0	2	0	4	0	0	3	2	0	7	4	0
23.03.08	0	0	5	0	0	0	1	1	0	0	0	0	0	2	0
30.03.08	46	13	41	15	25	14	9	12	9	14	4	32	19	12	36
07.04.08	71	18	54	18	31	17	12	14	10	19	6	45	31	15	49

Appendix.7. Weekly number of flowers under different yield group of cocoa grown under shade conditions

Date/T.No	<15 pods/tree/year					15-30 pods/tree/year					>30 pods/tree/year				
	1	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
01.04.07	5	0	5	2	3	0	2	8	1	0	0	4	3	0	3
08.04.07	1	2	2	0	3	0	0	6	0	0	0	3	0	0	2
15.04.07	14	3	8	0	6	0	0	2	2	0	0	2	1	0	0
22.04.07	0	0	4	0	4	0	0	0	0	0	0	0	0	0	0
29.04.07	7	0	0	4	2	0	3	8	7	3	0	6	4	1	0
06.05.07	5	9	0	4	4	0	1	6	5	0	0	3	7	0	0
13.05.07	0	0	1	0	2	0	0	0	0	9	0	0	0	0	0
20.05.07	8	6	11	14	2	5	3	15	51	11	3	11	8	6	9
27.05.07	6	0	3	6	6	4	0	7	7	5	4	6	7	9	4
03.06.07	0	0	0	2	0	3	0	0	3	0	3	3	1	6	1
10.06.07	1	1	0	1	1	1	0	2	0	1	1	2	4	3	0
17.06.07	0	0	0	2	0	0	1	2	1	2	1	1	2	1	0
24.06.07	0	0	0	1	0	0	0	2	0	1	0	0	0	0	0
01.07.07	1	1	3	0	0	2	0	2	1	1	3	2	0	0	0
08.07.07	1	0	0	4	0	0	0	0	1	1	4	1	1	0	0
15.07.07	0	1	0	0	0	0	2	1	0	0	1	0	0	2	0
22.07.07	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

29.07.07	0	0	0	0	0	4	0	0	2	0	1	0	0	0	0
05.08.07	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12.08.07	0	0	0	0	0	2	0	0	0	0	2	0	0	0	0
19.08.07	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26.08.07	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
02.09.07	0	0	0	1	1	0	0	1	0	1	1	0	0	1	0
09.09.07	1	0	0	0	0	0	0	0	0	0	0	0	0	3	0
16.09.07	0	0	0	1	0	3	0	0	0	0	1	0	0	0	0
23.09.07	0	0	0	0	0	2	0	0	0	0	1	0	0	0	0
30.09.07	0	0	0	0	0	0	3	2	3	0	1	1	0	0	0
07.10.07	0	0	0	0	0	2	0	0	0	0	1	1	0	0	0
14.10.07	0	0	0	1	0	0	0	0	0	4	0	0	0	0	1
21.10.07	0	0	0	0	0	0	3	0	3	4	0	0	1	0	2
28.10.07	0	0	0	0	0	2	0	0	4	0	2	0	0	0	1
04.11.07	0	0	0	3	0	0	0	0	3	0	0	0	0	2	0
11.11.07	0	0	0	0	0	18	0	9	7	6	13	0	0	9	6
18.11.07	0	0	0	0	0	7	0	5	1	3	9	0	0	2	2
25.11.07	0	0	0	0	0	13	0	7	7	6	10	0	0	10	5
02.12.07	0	0	0	0	0	5	0	3	1	0	4	0	0	3	0
09.12.07	0	0	0	1	0	4	0	3	0	3	6	0	0	0	0

16.12.07	0	0	0	0	0	3	2	2	2	0	4	2	0	2	4
23.12.07	0	0	1	0	0	1	1	0	3	1	6	0	0	0	7
30.12.07	0	0	3	0	0	3	0	0	0	6	2	0	0	0	3
06.01.08	3	0	0	2	1	2	0	1	2	5	2	0	0	0	3
13.01.08	6	0	3	2	2	8	5	6	5	6	12	4	0	0	8
20.01.08	0	0	0	1	2	4	3	2	1	5	18	4	3	3	3
27.01.08	0	0	2	13	2	3	3	0	3	3	18	6	10	0	5
03.02.08	0	0	4	6	0	5	5	0	6	3	18	7	5	0	0
10.02.08	1	1	4	1	1	2	20	2	1	6	2	6	2	0	3
17.02.08	36	3	0	3	2	17	3	2	9	9	10	7	4	0	6
24.02.08	23	0	6	6	6	19	6	5	15	18	15	13	5	0	0
02.03.08	18	4	5	6	8	18	11	10	10	15	14	13	5	0	6
09.03.08	6	4	7	9	5	5	3	14	3	11	6	4	5	6	6
16.03.08	1	0	0	0	2	0	0	0	0	2	0	2	0	0	0
23.03.08	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30.03.08	13	3	1	8	1	9	3	8	4	16	4	6	2	4	5
07.04.08	21	5	1	10	2	14	3	11	5	25	5	12	3	7	6

CROP WEATHER RELATIONSHIPS OF COCOA (*Theobroma cacao* L.)

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ABSTRACT OF THESIS

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ABSTRACT

A field experiment entitled “Crop weather relationships of cocoa (*Theobroma cacao* L.)” was conducted at the Department of Agricultural Meteorology, College of Horticulture, Vellanikkara from April 2007 to March 2008. The location is situated at 10^{o}31’ N and 76 ^{o}13’ E at an elevation of 25 m above the mean sea level in the central zone of Kerala. The experimental site is attached to the farm of Cadbury – KAU Co-operative Cocoa Research Project, Vellanikkara. The experimental cocoa trees were 20-year-old. A total number of 30 cocoa trees were selected, out of which 15 each were grown under shade and open conditions. The trees in shade were classified as plants giving yield of <15, 15-30 and more than 30 pods per tree per year and the plants in open were classified as plants giving yield of <60, 60-90 and more than 90 pods per tree per year. The biotic events viz., flowering and fruiting characters were recorded once in a week during the study period of one year. Daily meteorological data on maximum and minimum temperatures, relative humidity (morning and evening), rainfall and rainy days, bright sunshine hours, evaporation and cloud amount were collected from the Department of Agricultural meteorology, College of Horticulture, Vellanikkara. The investigations were undertaken with the objectives such as to study the seasonal influence on flowering and fruiting behaviour of cocoa, to find out the relationship between weather elements and biotic events of cocoa and to understand the impact of climate variability on cocoa production and productivity across the State of Kerala.

The biotic events viz., flowering, pod set and cherelle production in cocoa were seen throughout the year though weekly variations were significant and almost no biotic events were recorded in August. The pattern of biotic events in cocoa under open and shade were also similar. All the yield groups showed identical trend in flowering, pods set and cherelle production of cocoa irrespective of open and shade. However, the average number of flowers, pod set and cherelle was always lower in shade conditions when compared to the cocoa grown under open conditions. It is observed that the light availability on an average over cocoa under rubber (shade) was only 45 per cent, varying from 39 % (October) to 56 % (April). The overall percentage contribution of number of flowers, pod set and cherelle during summer was high when compared to that of the other

seasons. The flowering appears to be very low during the heavy wet spell due to mechanical damage as well as low bright sunshine available to the crop. It reveals that the light availability is very important for better performance of cocoa in terms of flowers, pod set and cherelle production.

The correlations between rainfall and flowering indicated that rainfall had negative (-0.464) relationship with flowering, as no significant flowering was seen during the heavy rainfall period from June-October. Nevertheless, the summer rains (February-May) two weeks before flowering influenced the flowering favourably. The positive relationship of cocoa flowering with maximum temperature was only due to flowering pattern of cocoa but not due to high maximum temperature (35-37°C) that prevailed during the summer. There was a positive trend between the helio-thermal units (HTU) and biotic events such as flowering, pods set and cherelle production in cocoa and significant at 0.01 level. The helio-thermal units depend on growing degree days, which is a function of temperature [(Max+Min/2)-10°C] and number of daily sunshine hours.

The number of pods harvested was more in October and November, followed by summer (February-April) in contrast to the mean trend where the mean yield was more during summer followed by post monsoon season. The pattern of pod harvest was different between the habitats (open and shade) as the peak harvest in shade appeared during February – March while October – November in open. The coefficient of variation was very high (48.9-124.3 %) in monthly pod yield of cocoa while it was less (23 %) in the case of annual yield of cocoa. It indicated that the monthly cocoa yield is very sensitive to extreme weather conditions. The study also revealed that there was a sharp decline in cocoa area while increase in production and productivity due to technological interventions. However, the inter-annual variations in cocoa yield could be related to weather aberrations and it had no biennial bearing tendency.

The pods harvested during November (post monsoon season) was superior in pod weight (562g), pod length (17.03 cm) and bean weight (1.28). The pods harvested during September (rainy season) and January (winter) showed intermediary, having the pod weight of 555 g/pod in September and 524 g/pod in January. The pods harvested during summer recorded 44 and 29 per cent less in pod weight and bean weight, respectively when compared to post monsoon season. Hence, a harvest of five pods during the post and southwest monsoon seasons equals to nine pods harvested during summer season, 5.4 pods during winter while 5.1 pods in south west monsoon. The study reveals that the low pod and bean weights during summer were due to high number of pods produced, moderate to severe soil moisture stress and high maximum temperature including temperature range.

The maximum temperature from January to March had a profound influence on annual cocoa yield. The relationship between growing degree days (GDD) and yield also indicated similar trend as in the case of maximum temperature. The mean maximum temperature during summer was high in poor yield years while less in good yield years. There was an inverse trend between the annual rainfall and cocoa yield. It was found that the difference in cocoa yield during rainy months was very significant followed by post monsoon between good and bad yield years and thus the adverse influence of heavy rain on cocoa yield. On an average, the decline in yield was 45 per cent in bad yield years when compared to the mean yield while 45 per cent increase in good yield years during the southwest monsoon. The percentage increase in yield during good years when compared to that of bad years was 72 and 58 per cent during southwest monsoon and post monsoon, respectively. On examination through step wise regression, it was understood that the model explained 43 per cent variation in pod yield of cocoa due to maximum temperature alone. It revealed that high maximum temperature during summer with heavy rainfall during rainy season is likely to affect the annual cocoa yield adversely up to 40-50 per cent. Similar results were obtained when the secondary data on annual cocoa yield at the State level was subjected to crop weather analysis. From the above, it is clearly understood that high maximum temperature during summer, high rainfall and low light availability during the rainy season are the main factors limiting the cocoa production and productivity over the humid tropics.