Crop weather modelling of cocoa production in humid tropics under the purview of climate change

by

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THESIS

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DECLARATION

I, Vishnu R P. (2013 – 20 – 116) hereby declare that this thesis entitled **"Crop Weather Modelling of Cocoa Production in Humid Tropics Under the Purview of Climate Change"** is a bonafide record of research work done by me during the course of research and the 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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SYMBOLS AND ABBREVATIONS

TSS	Total Soluble Sugar
BSH	Bright Sunshine Hours
SUCROS	Simple and Universal Crop growth Simulator
WMO	World Meteorological Organization
IPCC	Inter government panel on Climate Change
GCM	General Circulation Model
RMSE	Root Mean Square error
NS	Non-significant
RCP	Representative Concentration Pathway
AR5	Assessment Report 5
GDP	Gross Domestic Product
CPCRI	Central Plantation Crop Research Institute
ICAR	Indian Council of Agricultural Research
KAU	Kerala Agricultural University
T_{max}	Maximum temperature
T_{min}	Minimum temperature
GHG	Green House Gases
CRI	Cocoa Research Institute
FSE	Fortran Simulation Environment
FAO	Food and Agricultural Organization
WS	Wind speed
EVP	Evaporation
LAI	The leaf area index
WTOT	Actual total biomass

WRT	Actual root biomass
WPD	Actual pod biomass
WLV	Actual leaf biomass
WWD	Actual wood biomass
RAMS	Regional Atmospheric Modelling System

Chapter 1. Introduction

The growing global consensus built on evidence that the world is facing a threat from climate change has sustained the feeling and belief that many countries in tropical and sub-tropical regions be more susceptible to the bizarre phenomenon. The condition will be most severe in under developed and developing countries where information on climate change is the poorest, technological change has been the slowest, and the domestic economies depend the most heavily on agriculture. Climate change is a possible threat that will affect the agriculture by making reduced availability of natural resources like water and soil.

Agriculture is always vulnerable to unfavorable weather events and climate conditions. Despite scientific advances such as improved crop varieties and irrigation systems, weather and climate are still vital factors in agriculture productivity. Climate change is defined as a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods. The mounting temperatures and carbon dioxide and uncertainties in rainfall associated with climate change may have serious direct and indirect consequences on crop production and hence food security

Cocoa (*Theobroma cacao* L.) is the only source of chocolate and is the greatest treasure ever discovered by man. Cocoa cultivates almost exclusively from 20.0° either side of the equator in an area known as the tropical belt; and because it is rather narrow, the number of countries in which it may be grown productively is very limited. Annual mean temperatures between 23.0°C and 25.0°C and rainfall of 1500-2500 millimeters are ideal for cocoa cultivation. It is crucial to know the average monthly temperature and monthly water balance for cacao because all physiological processes such as vegetative and reproductive growth are regulated by these factors. Very strong winds are harmful to cocoa.

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Agricultural crops are sensitive to climate variability and weather extremes of droughts, floods and severe storms. Climate change is projected to have an effect on agriculture and the net result could be harmful or beneficial. Climate change has large consequences for the future of cocoa production and community livelihoods. Farmers in developing countries already face declining productivity rates due to a lack of access to extension services, credit, and quality farm inputs such as seeds and fertilizer. Furthermore, increased temperature and rainfall variability has the potential to exacerbate environmental degradation on cocoa producing areas.

Worldwide number of people depends upon cocoa for their lively hood and it comes to 40-50 million. In India, Cocoa is being cultivated in the States of Kerala, Karnataka, Andhra Pradesh and Tamil Nadu in an area of 78000 ha with total production of 16,050 MT. Tamil Nadu ranks first with an area of 26,969 ha whereas Andhra Pradesh ranks first in production. The highest productivity is in Kerala which is 785 kg/ha. The average productivity of cocoa in India is 475 kg/ha (Table 1). Comparing to global productivity (per ha) India is no way nearer to the global situation.

Table.1. Area, production and productivity of cocoa over India

State	2014-15		
	Area (ha)	Production (MT)	Productivity (kg/ha)
Kerala	14650	6000	785
Karnataka	12906	2000	525
Tamil Nadu	26959	1750	265
Andhra Pradesh	23485	6300	550
Total	78000	16050	475

Source: Directorate of Cocoa and cashew Development, Kochi

Therefore, it is important to understand the effect of weather on growth and development of cocoa to minimize the crop losses due to aberrant weather. A climate-crop coupled model, in which a crop growth model is coupled to a climate model, is one tool to assess the influence of the climate-crop interaction. The present study is for assessing the impact of climate change on cocoa production.

Hence, the present experiment was undertaken to understand the effect of weather variables and impact of climate change on yield and yield attributes of cocoa with the following objectives:

1. Development of crop weather relationship for Cocoa (*Theobroma cacao* L.) under tropical humid climate of Kerala.
2. Study the impact of climate change on cocoa production using simulation model.

The growth and yield of any crop is highly associated with environmental factors. Interactions between crop and weather are the backbone for the productivity and stabilized yield. Climate change alters weather conditions considerably which is sufficiently evident from observations all around the world. Climate change alters weather variables and there by affect the production of rice. General Circulation Models (GCM's) are very useful in predicting the future climate. Crop weather simulation models with the help of GCM's can estimate the impact of future climate conditions on production of rice. In this chapter we are going to review the effect of different weather variables on cocoa and how the climate change is altering weather and its impact on the cocoa production is being reviewed.

2.1 CLIMATE CHANGE IMPACT ON COCOA

Climate change is one of the major issues facing humankind. While previously cast as a future condition to be avoided, there is mounting evidence that climate change is already happening and that its impacts are rising day by day (IPCC 2001).

According to (WMO, 2013) Climate change emerged as the major risk affecting the environment and water resources. Increased emission of greenhouse gases like carbon dioxide (CO2), methane (CH4) and nitrous oxide (N2O) is the main reason behind this radical change in the global climate (FAO, 2013). Global combined surface temperatures over land and sea have been increased from 13.68°C in 1881-90 to 14.47°C in 2001-10).

The effect of extreme events like heat waves, droughts, floods, cyclones, and wildfires occur is more in the changing climate and the mean global surface air temperature increased by 0.74°C (0.56 to 0.92) °C in past 100 years (IPCC, 2007). Anim-Kwapong and Frimpong (2005) reported that cocoa is highly sensitive to climate change particularly temperature.

Almost all varieties showed maximum potential during post monsoon season. Increase in pod and bean characters during post monsoon period can be attributed to favourable condition prevailed during monsoon (Egbe and Owolabi, 1972). Similar report was also given by Rubeena (2015) in her studies

Deressa *et al.,* (2008) that reported increased intensity and duration of sunshine and rainfall variability on the African continent. The minimum temperature of 23°C was maintained, this showed why productivity was maintained, Boyer (1970) reported that a drop below 23°C reduced flowering in Cocoa. Apart from all other crops, the cocoa subsector contributed 13.3% agriculture's share of Gross Domestic Product (GDP) in Ghana 2012 (Ghana Statistical Services, 2012).

In most parts of Sub-Saharan African areas where dry land farming is very common, over reliance on rain-fed agriculture increases farmers vulnerability to adverse effects of climate change (Mertz, Mbow, Reenberg, & Diouf, 2009). From Codjoe *et al.*, (2013) cocoa farmers in Ghana adopted five main coping and adaptation strategies, they are, shade management strategy, soil fertility strategy, land preparation strategy, diversification of crop, lining and pegging strategy. Cocoa has played a major role in the conservation of forest and biodiversity of both Ghana and Ivory coast, on the other hand cocoa has an important factor in forest conversion for agriculture (Ruf *et al.*,2004).

2.2. COCOA AND WEATHER

The prolonged dry seasons result in cocoa seed mortality, whereas short dry seasons result in decreased pod filling, which affect the size of the beans. The fluctuations of weather may cause serious environmental hazards. In this chapter mainly shows the recent research works on cocoa.

2.2.1 Temperature

Seasonal temperature is an important climatic factor which can have thoughtful effects on the yield of crops. Changes in seasonal temperature affect the grain yield, mainly through phenological development processes.

Temperature will be the primary factor to control cocoa production, the effect of weather may produce serious pest/pathogen attack (Christisnsen, 1986). In the tropical cocoa growing areas temperature lies maximum of 30-32°C and minimum of 18-21°C and absolute minimum of 15°C, due to unfavourable conditions the plant will get into leaf defoliation, reduced yields and pest/pathogen attack (Wood and Lass,1985).

The changes in temperature will affect the phenological process of plant, phenology is an indicator of Global warming (Chmielewski and Rotzer 2000).

The Black pod disease will be most destructive one, around 50% of the cocoa farm crops were affected by serious Black pod disease. The disease is very much associated to Weather and climatic conditions (Idachaba & Olayide, 1976; and MASDAR, 1998). The studies made by Green Wood and Posner (1950) in Ghana reported that leaf flushing will be controlled by temperature, and the weekly mean of daily maximum temperature must be at least 28.3°C for flushing initiated.

Wood and Lass (1985) studied that in the West Africa temperature vary more than any other cocoa growing countries. Daily, seasonal, annual differences of climatic and weather parameters having greater importance to plant growth (Ayoade, 2004).

Sale (1968) is noticed that at constant temperature 23.30°C very little flushes were produced and at 30°C most of the flushes are produced, an increase in day or night temperature it increases the number of flushes.

A reduction in flowering is observed in cocoa as temperature drops below 23°C (Boyer,1970). Daymond and Hadley (2004) were found that 25°C will be then optimum temperature for cacao photosynthesis.

(White. *et al.*,1999; Kramer *et al.*,2000) reported that the changes on weather variables might influence net photosynthesis, pollination, flowering and yield. Several reports indicating similar impacts on weather changes in several other crops. Harun and Hardwick (1988) found that rate of photosynthesis changed between 200C and 300C.

2.2.2 Rainfall

Alvim (1966) reported that the environmental factors like Rainfall, and temperature are having more significant influence flowering and pod setting.

Wood and Lass (1985) observed that in Ivory Coast Rainfall vary from 1200mm in the cocoa growing areas, and nearly 3,000 mm in West Cameron and Nigeria. The major cocoa cultivating areas lies in between 1250mm and 2800mm.the annual rainfall may excess of 2500mm will lead to Vascular streak die back and other fungal diseases. In the cost of Venezuela cocoa growing under irrigation, the annual rainfall is lies between 850-1000mm.

The studies made by Adams and Mc Kelvie (1955) in Ghana most of the cocoa cultivating areas having a short, mild, dry season, cocoa was limited in those areas received rainfall more than 250mm in between November and March. Purseglove (1974) is studied about the rainfall on cocoa cultivating areas to be 1010 to 2540mm. The effect in soil moisture on seedling growth were studied at Cocoa Research Institute, Ghana (CRI,1972).

(Jose *et al.,* 2008; CPCRI,2015) found that around 90% of the yield loss is due to fruit rot disease, heavy rainfall will be the reason for fruit rot disease. Wood and Lass (1985) studied that the cocoa grows satisfactory in West Africa where the annual rainfall total is 1300-1500mm, West coast of India and Kerala the annual rainfall is exceeds to 3000mm, during the last five months of dry season cocoa must needed irrigation.

Well distributed rainfall that means above 1200mm a year is the most suitable for growth Asopa and Narayanan (1990). The plant requires an annual rainfall of 1500-2000mm for a minimum of 90-100mm per month (ICAR, 2002).

2.2.3 Relative Humidity

Wood and Lass (1985) had observed higher relative humidity in cocoa cultivating areas, often 100% at night that falls to 70-80% by day, and sometimes lowers in the dry season, and the spread of fungal diseases and difficulties of storage and drying was also observed due to relative humidity.

In tropical environments under daylight conditions the temperature and relative humidity in the top two thirds of the canopy are comparable with the conditions of the surrounding atmosphere whereas these properties of the air at the canopy base are strongly decoupled (Shuttleworth *et al.*,1985).

High photosynthetically active radiation, low relative humidity and moisture stress lessens stomatal conductance in cocoa (Balasimha and Rajagopal, 1988).

Studies conducted by Harun and Hardwick (1988) regarding the effect of temperature and water vapour deficits on photosynthesis and transpiration of cocoa leaves by using infrared analyzers observed a constant photosynthetic rate with low water vapour pressure deficit up to 10 m bar and also with an increasing water vapour pressure deficit. An increase in stomatal resistance was noted with increased water vapour pressure.

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According to Dakwa (1977), the development of black pod disease (a highly infectious disease in cocoa, which can destroy a cocoa farm within eighteen to twenty-four (18-24) months which is caused by a fungus called phytophthora spp) in cocoa growing belt in West Africa was linked to relative humidity which was significantly correlated with the research conducted by him. However, the seemingly high number of farmers (91%) also agreed with the statement that the fact increasing black pod disease is highly aided by high rainfall (high humidity) into their farms. Relative Humidity during morning and evening had a negative influence on flower production in cocoa plants and the maximum influence was noticed during the initial eight weeks prior to flowering (Prameela, 1997).

2.2.4. Sunshine

Alvim (1958) used the infiltration technique to display the degree of stomatal opening in cocoa, and showed, with cutting sand young plants, that the technique could be used as a practical indicator of water stress in cocoa. In a field study with five-year-old plants, which were not suffering from water stress, stomatal opening increased as the light intensity increased with maximum opening in strong sunlight.

Studies conducted by Soria (1970) in the two localities of tropical rainforest climatic conditions in Costa Rica regarding the annual flowering and pollination of cocoa. Couprie (1972) showed that the sunshine had a negative but non -significant result on fruit set and Cherelle wilt.

The amount of sunlight that falls on cocoa tree will affect its growth and yield, a shade experiment is conducted in Trinidad show that 50% shade is optimum for young cocoa, but 50% of the shade in Trinidad allow quiet different amount of solar energy to fall on the tree as compared with 50% shade in Ghana (Wood and Lass ,1985). Bright sunshine hours could have enhanced flowering and maximum correlation noted seven weeks prior to flowering (Prameela,1997).

2.2.5. Wind

In cocoa the combined effect of solar radiation and wind could result in severe mechanical injuries at the pulvinus region (Alvim *et al.,*1972).

The violent wind and hurricane may reason for severe damage to basal chupon.in the case of young plants physical damages caused by wind blow in this case sensitivity of cocoa plant having greater importance, where such wind occur should protected using wind breaks (Wood and Lass ,1985).

According to (Balasimha,2002) by varying intensity in different cocoa producing areas, wind could cause undesirable effect on cocoa causing premature leaf fall. In west Africa harmattan-the dry wind which blows from the Sahara for a variable period between December and March causing Cherelle's and flowers drop of in Ivory cost areas (WCF,2008).

2.3. WEATHER AND BIOMETRIC PARAMETERS OF COCOA

2.3.1. Yield

Couprie (1972) observed 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.

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°C.

2.3.2. 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).

A matured cocoa plant can produce thousands of flowers per year, sometimes more than 50,000 but less than 5 per cent are pollinated and an even smaller in proportion (Alvim, 1984).

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 a greater number of flowers per cushion per week. Couprie (1972) showed that flowering was greater when daily temperature variation was least.

Madhu (1984) noticed 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).

2.3.3. Pod and bean characters

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, maximum 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) analysed the bean characters with regard to weather conditions and found higher pulp percentage and lower total soluble solids and bean weight in wet period is compared to dry season.

2.3.4. Shade

Freeman (1929) is recorded in his 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°C no flushing took place.

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 action against the harmful effects extreme environmental fluctuations (Evans and Murray, 1953). Overall flower production is considerably higher in the sunny habitat than 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).

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).

2.3.5. 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. Alvim (1965) reported that the scarcity of flowers from June to September was attributed to the indirect effects of low temperature. The non-flowering period was July– September.

At the beginning of the wet season, there was a burst of flowers which resulted in the main crop after five to six months (Alvim, 1966).

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). 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.

2.3.6. Fruiting behaviour

Alvim (1974) studied the pattern of climate and cropping of cocoa in West Africa. 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.

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. 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).

Wood (1985) also showed that there were one or two peak har vest 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.

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. COCOA MODELLING

SUCROS-Cocoa (CASE2) has been used in this study to model the effect of weather parameters on crop growth and yield. SUCROS-Cocoa is largely based on the and INTERCOM SUCROS (Van Laar *et al.*, 1997). Input parameters required to run the model are weather data include precipitation, radiation, minimum and maximum temperature, and vapour pressure, for a period of at least 8 years. There are three types of weather data may be used as an input: (1) daily weather, (2) monthly weather data (Hijmans *et al.*, 1994). CASE2 is a physiological model that simulates cocoa growth and yield for different weather and soil conditions and cropping systems Zuidema *et al.*, (2003).

The SUCROS-Cocoa model exploits a large amount of published knowledge on the physiology and agronomy of the cacao tree. this model also uses weather and soil data and information on cropping system Zuidema *et al.,* (2002).

(Zuidema & Leffelaar 2002) were noticed a brief description of the simulation model CASE2. that has been used to obtain the simulation results for the study. Only those aspects of the model that are necessary to understand the model output are explained in this chapter. A more complete description of the model is included in a separate report. Validation is the comparison of the results of model simulations with observations that were not used for the calibration, the experimental data collected were used for independent model validation (Goudriaan & Van Roermund 1999).

The CASE2 model has been developed using existing knowledge on physiology and morphology of the cacao tree. The current model makes use of almost all published and relevant information on the cacao tree. Further model development therefore requires new insights into cacao growth and new estimates for important model input parameters (Van Ittersum *et al.*, 2003). (Anten *et al.*, 1993) were studied about the full documentation of SUCROS-Cocoa (earlier presented as CASE2 version 2.2)

2.5. CLIMATE CHANGE AND CLIMATE VARIABILITY

Accelerated warming of the atmosphere can jeopardize the global economy through ecosystem changes. Further, elevated ambient temperature can also alter the evapotranspiration and the form of precipitation thereby variably impacting monthly stream flow patterns (Chien *et al.*, 2013). As per IPCC Representative Concentration Pathways 8.5 projections global mean surface temperature may experience an increase by 2.6°C to 4.8°C by the end of 21st century (IPCC, 2013). An increase in the mean surface temperature (1.5°C) during monsoon season was predicted in the decade 2040-2049 with respect to 1980s (Saseendran *et al.*, 2000). Studies showed that southwest monsoon rainfall and annual rainfall was decreasing, but post monsoon rainfall as increasing (Krishnakumar *et al.*, 2008; 2009). Climate change is considered to affect water resources through increased/ unusual spatio- temporal variability long term temperature and water balance changes which would in turn affect the water and food security, human health and their livelihood and ecosystem (Vorosmarty *et al.*, 2000).

Increasing water stress has been anticipated from the global assessment of water resources in many parts of the world under the projected climate change and population growth scenarios (Arnell *et al.,* 2001).

The study conducted by Nair *et al.,* (2014) using monthly precipitation data obtained the results of maximum seasonal coefficient of variation in precipitation during winter preceded by pre-monsoon and post monsoon periods, while the monsoon precipitation had shown minimum seasonal coefficient of variation for the entire districts of Kerala. The month of January, July and November had shown a declining trend in rainfall from 1901-2000 in most districts. Sreekala *et al.,* (2015) studied the recent trends in rainfall of different districts of Kerala. Annual mean rainfall of all districts as well as their coefficient of variation was determined and Mann Kendall trend test was used to find out the significance of the trend. A decreasing trend in North East monsoon was also observed with a trend value of -1.1 but summer rainfall had shown a positive trend with a trend value of 1.6 at 10per cent significance level. An increasing trend was observed in winter rainfall also.

General Circulation Models (GCMs), modelled the global climate provide projections at various resolutions and there were differences between the various models in projected climate change values for each grid cell and they were regarded as 20 the entry points for the conservation assessments of climate change since only these models provides estimates of future climate change due to the greenhouse gas forcing's (Hannah *et al.*, 2002). Increased carbon di oxide concentration in atmosphere can affect the crop yield seriously. Increased CO2 concentration is thought to stimulate plant growth and decrease water requirements (Gitay *et al.,* 2001). According to IPCC, by 2020 severe water stress had been predicted in some parts of India due to rise in temperature and depletion in summer rainfall by the influence of climate variability on Indian subcontinent (Cruz *et al.,* 2007).

IPCC (2001) defines adaptive capacity as the ability of a system to adjust to climate change, including climate variability and extreme events, to moderate potential damages and cope with the consequences. In some areas skills are required for identification and analysis of policies affected by climate change, effectively communicate impacts and adaptation responses to policy makers, integrated policy formulation, planning and coordination; evaluation and modification (Kimenyi *et al.,* 2004).

2.6. CLIMATE CHANGE IMPACT ON AGRICULTURE

Naresh *et al.* (2011) reported that Indian agriculture is facing challenges due to several factors such as increased competition for land, water and labour from non-agricultural sectors and increasing climatic variability. The climate variability associated with global warming will result in considerable seasonal or annual fluctuations in food production.

Pratap *et al.* (2014) analyzed the changes in climate variables, viz. temperature and rainfall during the period 1969-2005 and has assessed their impact on yields of important food crops. A significant rise was observed in mean monthly temperature, but more so during the post-rainy season. The changes in rainfall, however, were not significant. An increase in maximum temperature was found to have an adverse effect on the crop yields. A similar increase in minimum temperature had a favorable effect on yields of most crops, but it was not sufficient to fully compensate the damages caused by the rise in maximum temperature. Rainfall had a positive effect on most crops, but it could not counterbalance the negative effect of temperature. The projections of climate impacts towards 2100 have suggested that with significant changes in temperature and rainfall, the rice yield will be lower by 15 per cent and wheat yield by 22 per cent.

Morison *et al.* (2008) reported that agriculture accounts for more than 80 per cent of all freshwater used by humans, most of that is for crop production. Currently most of the water used to grow crops is derived from rain fed soil moisture, with non-irrigated agriculture accounting for about 60 per cent of production in developing countries. Though irrigation provides only 10 per cent of agricultural water use and covers just around 20 per cent of the cropland, it can vastly increase crop yields, improve food security and contribute about 40 per cent of total food production since productivity of irrigated land is almost three times higher than that of rain fed land.

Antle (2010) conducted a study on the changes in crop production and yield associated with climate change. Climate-induced water scarcity from changes in temporal and spatial distribution of rainfall could lead to increased competition within the agriculture sector and with other sectors.

Lobell (2011) reported that climate change will influence crop distribution and production and increase risks associated with farming. Crop yields have already experienced negative impacts, underlining the necessity of taking adaptive measures

Mo *et al.* (2013) reported that impact of climate change on crop evapotranspiration becomes important for water management and agricultural sustainability. The warmer climate may increase the ET_0 of crops leading to greater demand for irrigation water. Climatic factors like radiation, humidity, wind speed and rainfall also influence the ET_0. Consequently, any variation in those factors will also modify the ETc.

Falguni and Kevin (2013) reported that climate change is likely to have impact on the hydrological cycle and consequently on the available water resources and agricultural water demand. There were concerns about the impacts of climate change on agricultural productivity. Industrialization and the extended use of fossil fuels have lead to a great increase in the atmospheric concentrations of greenhouse gases. With respect to the relations between the hydrological cycle and the climate system, every change on the climate could affect parameters such as precipitation, temperature, runoff, stream flow and groundwater level. This could lead to changes in the crop water requirement in agriculture and also industrial and domestic water consumption demands will also change.

2.7. CLIMATE CHANGE AND WATER REQUIREMENT

Rapid industrialization over the last century has brought out industrial and agricultural emissions of carbon dioxide (CO_2), Methane (CH_4), Chloro fluro carbon (CFC), Nitrogen oxide (NOx) and other gases. It resulted in an increase of greenhouse gases in the earth's atmosphere. Carbon di oxide concentration is found to increase at the rate of about 1.5 ppm per year (Keeling *et al.,* 1984). General circulation models (GCM) describing the dynamic processes in the earth's atmosphere have been used extensively to provide potential climate change scenario (Gutowski *et al.*,1988).

Saini and Nanda (1987) found that increased temperature hasten the rate of leaf senescence resulting in reduction in leaf area. The model simulation revealed that warming scenarios will have an adverse effect on rice production through the advancement in maturity and reduction of source size coupled with poor sink strength in state of Punjab. Similarly, the decrease in crop life span and grain yield with increase in temperature is also reported (Hundal *et al.* (1993).

Climate change scenarios include higher temperatures, changes in precipitation, and higher atmospheric carbon dioxide concentrations which may affect yield, growth rates, photosynthesis and transpiration rates, moisture availability, through changes of water use agricultural inputs such as herbicides, insecticides and fertilizers. Environmental effects such as frequency and intensity of soil drainage leading to nitrogen leaching, soil erosion, land availability, reduction of crop diversity may also affect agricultural productivity. An atmosphere with higher carbon dioxide concentration would result in higher net photosynthetic rates (Cure and Acock 1986).

According to current GCM prediction, a doubling of the current CO_2 level will bring about an increase in average global surface air temperature of between 1.5 and 4°C with accompanying changes in precipitation patterns (Gates *et al.*, 1992).

Watson *et al.* (1996) reported that the changing climate may accelerate the hydrological cycle resulting in changes in precipitation, evapotranspiration, run-off, and in the intensity and frequency of floods and droughts. Both changes in rainfall and temperature affect crop growth and development.

Global climate change is a change in the long-term weather patterns that characterize the regions of the world. The term 'weather' refers to the short-term (daily) changes in temperature, wind, and/or precipitation of a region (Merritts *et al.* 1998).

Atmospheric carbon dioxide concentration has risen and the general circulation models have predicted a global temperature rise of 2.8-5.2°C for a doubling of atmospheric carbon dioxide concentration. Doubling of carbon dioxide will decrease leaf stomatal conductance to water vapour to about 40 per cent. Water use efficiency by C_3 crop plants under field conditions has usually seen to be decreased. A yield enhancement 30-35 per cent for C_3 crops occurred for a doubling of carbon dioxide. Transpiration rates are found to increase for an increase in the atmospheric temperature. Under well-watered conditions evaporation will increase about 4-5 per cent per 1°C rise in temperature (Allen, 2004).

Schmidhubber and Tubiello, (2007) investigated the spatial and temporal variation of the water requirement, water consumption and water deficit as affected by the changing weather patterns in the period from 1976 to 2005. Most agricultural climate change impact studies have focused on the impact on crop productivity. Changes in temperature, radiation and precipitation not only affect productivity but also have an impact on plant water use.

Agriculture being the number one water user across the globe, changes in agricultural water use will have large impacts on water availability.

Supit *et al.* (2010) analyzed the trends in European seasonal weather conditions and related crop water requirements, crop water consumption and crop water deficits the period 1976–2005. The impacts of the changing weather patterns differ per crop and per region. In various European regions the wheat water requirement showed a downward trend which can be attributed to a shorter growing season as a result of higher temperatures in spring. Changes in these variables can be attributed to the combined effect of variations in crop water requirements and rainfall.

Chattaraj *et al.* (2014) reported that the crop water requirement under the projected climate change could be mediated through changes in other weather parameters including the air temperature

2.8. ASSESSMENT OF CLIMATIC CHANGES

For the assessment of climate change on biodiversity, several tools were used which included global climate models, regional climate models, dynamic and equilibrium vegetation models, species bioclimatic envelope models and site-specific sensitivity analysis (Sulzman *et al.*,1995). Equilibrium simulations which used a step increase in CO2 showed the increasing temperatures in both hemispheres, but transient simulations showed both the ups and downs in the temperature distribution (Sulzman *et al.*, 1995).

Regional models could be used along with the Global Circulation Models (GCMs) which gave more resolution. MM5 (Mesoscale Model version 5) and RAMS (Regional Atmospheric Modelling System) were the two major regional models that were widely used (Sulzman *et al.,* 1995). The climate dynamics of southern hemisphere and northern hemisphere were different, so models developed with primary focus for a particular hemisphere would not yield good results in the other hemisphere (Grassl, 2000).

For determining the local climate change, regional models were more useful than that of global models which depended on global forcings (Pitman *et al.*, 2000). These models could represent the land-use changes and its effect on cloud formation mechanisms. But the results of these models were not easily available for all regions. GCM and regional climate models were used by dynamic vegetation models, forest gap models, biome envelope models and species envelope models in order to give light into different aspects of the biogeography of future climate change (Cramer *et al.*, 2000).

General Circulation Models (GCMs), modelled the global climate provide projections at various resolutions and there were differences between the various models in projected climate change values for each grid cell and they were regarded as the entry points for the conservation assessments of climate change since only these models provides estimates of future climate change due to the greenhouse gas forcings (Hannah *et al.*, 2002). The assessments were improved by opting results from transient (not equilibrium) simulations of CO2 increase and models which was completely coupled with ocean and atmosphere to the regions of interest (Hannah *et al.,* 2002).

The field experiments were conducted during 2017-18 to develop Crop weather model for cocoa production in the humid tropics under the purview of climate change. The materials used and methods followed are described below:

3.1. DETAILS OF FIELD EXPERIMENT

3.1.1. Location

The experimental site is located in the farm of Cocoa Research Station, Vellanikkara. The station is located at 10°31' North latitude and 76° 13' East longitude at an elevation of 45 m above mean sea level and is situated in the central zone of Kerala.

3.1.2. Climate

The area experiences a typical warm humid climate and receives average annual rainfall of 2663 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 dry spell from November. The following are the seasons considered for this study.

Summer:	March - May
Southwest monsoon:	June to September
Post monsoon:	October - November
Winter:	December - February

3.1.3. 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 presented in Table 2

Table 2. Physico-chemical properties of soil in the experimental field

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 ammonium acetate extraction (Jackson, 1958)

3.1.4. Variety

Cocoa Hybrid 309.9 developed from Cocoa Research Station, Vellanikkara was used for the study. The parents of the hybrid are GVI55 and Criollo.

3.1.5. Treatments and notations

The study was conducted in three consecutive years with randomized block design with five replications.

Table 3. Treatments and notations

Treatments	Notation
2012 summer	T1
2012 Monsoon	T2
2012 Post monsoon	T3
2013 summer	T4
2013 Monsoon	T5
2013 Post monsoon	T6
2014 summer	T7
2014 Monsoon	T8
2014 Post monsoon	T9

3.3. OBSERVATIONS

Observations on growth and yield parameters were recorded at Cocoa Research Station on randomly selected plants in each replication for each treatment after leaving the border rows were used for the study. Growth observations were taken at weekly intervals. Observations were taken as per standard procedures.

3.3.1 Biometric characters

3.3.1.1. Total number of flowers per tree

Cocoa being a year-round bloomer with flowers all over the tree, a sampling procedure was adopted for taking weekly flower counts. Two-meter 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).

3.3.1.2. Total number of pod set per 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.

3.3.1.3. Total number of Cherelle per tree per 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.

3.3.1.4. 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.

3.3.1.5. Pod and bean characters:

Pod and bean characters like pod weight, wet bean weight, total pod yield per year and total soluble sugar was recorded once in a season. To measure the bean weight, the fruits collected from the trees were broken and beans were manually separated.

3.4. WEATHER OBSERVATIONS

The data on the different weather elements were collected from the Agromet observatory of College of Horticulture, Vellanikkara, Thrissur

Table 4. Weather parameters used in the experiment

No.	Weather parameter	Unit
1	Maximum temperature (Tmax)	°C
2	Minimum temperature (Tmin)	°C
3	Rainfall (RF)	mm
4	Relative humidity (RH)	Per cent (%)
5	Bright Sunshine hours (BSS)	hrs
6	Wind speed (WS)	km hr^{-1}
7	Evaporation (EVP)	mm

3.5. SOIL DATA

The result of soil analysis of experimental site was presented in Table 5.

Table 5. Soil analysis of the experimental site

No	Parameter	Availability
1	Organic carbon (Per cent)	1.00
2	Available Phosphorous (kg ha^{-1})	16.50
3	Exchangeable Potassium (kg ha^{-1})	117.60
4	Available Nitrogen (Per cent)	2.50

3.6. STATISTICAL ANALYSIS

The data recorded from the field experiment was analyzed statistically using Analysis of variance technique. Randomized block design was used in the analysis of weather and crop data.

Correlation and regression analysis were done between the growth and yield characters with the weekly mean/total values of rainfall, maximum temperature, minimum temperature, relative humidity and sunshine hours to determine the effect of weather elements on the growth and yield of rice. Regression equations were worked out from these observations.

The different statistical software like Microsoft – excel and SPSS were used in the study for various statistical analyses.

3.7. CROP WEATHER MODEL

SUCROS-Cocoa (CASE2) has been used in this study to model the effect of weather parameters on crop growth and yield. Model developed by the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT). Cacao Simulation Engine for water-limited production. CASE2 is a physiological model that simulates cocoa growth and yield for different weather and soil conditions and cropping systems. The model serves the following purposes:

1. To estimate cocoa yields in relation to weather and soil conditions and cropping systems;
2. to obtain insight in factors determining production;
3. to integrate existing knowledge on the physiology and morphology of cacao trees; and
4. to identify gaps in knowledge in the physiological basis for estimating cocoa growth and yield.

Input parameters required to run the model are weather data include precipitation, radiation, minimum and maximum temperature, and vapour pressure. Soil data include information on the amount, thickness and physical characteristics of soil layers. Cropping system data include information on planting density, age at the start of the simulation and characteristics of shade trees. Plant characteristics include parameters that are used to calculate rates of photosynthesis, respiration and transpiration; parameters that are used to distribute biomass over plant parts (over leaves, wood, roots and pods); vertical distribution of roots in the soil; ripening and growth of pods; leaf age, etc. Part of the input parameters for CASE2 are time specific. Weather information (temperatures, rain, radiation and vapour pressure) is specific for one day or for one month. In the latter case, daily values are generated by the model on the basis of the number of rain days. Input parameters on plant physiology and morphology, on soil characteristics and on cropping system are constant over time.

3.7.3 *Validation of CASE2 model*

Validation is the comparison of the results of model simulations with observations that were not used for the calibration. The experimental data collected were used for independent model validation. Statistical index used for model validation is

$$\text{RMSE (Root Mean Square Error)} = \sqrt{\frac{\sum_{t=1}^{n}(\text{Pi} - \text{Oi})^2}{\text{n}}}$$

Where Pi and Oi refer to the predicted and observed values for the studied variables (e.g. grain yield and total biomass) respectively and n is the mean of the observed variables.

3.8. CLIMATE CHANGE SCENARIOS

Impacts of climate change depends not only on the response of the Earth system but also on how humankind responds. These responses are uncertain, so future scenarios are used to explore the consequences of different options. The scenarios provide a range of options for the world's governments and other institutions for decision making. Policy decisions based on risk and values will help determine the pathway to be followed.

The Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) has introduced a new way of developing scenarios. These scenarios span the range of plausible radiative forcing scenarios, and are called representative concentration pathways (RCPs).

RCPs are concentration pathways used in the IPCC Assessment Report5 (AR5). They are prescribed pathways for greenhouse gas and aerosol concentrations, together with land use change, that are consistent with a set of broad climate outcomes used by the climate modelling community. The pathways are characterised by the radiative forcing produced by the end of the 21st century. Radiative forcing is the extra heat the lower atmosphere will retain as a result of additional greenhouse gases, measured in Watts per square meter.

Table 6. Description of representative concentration pathway (RCP) scenarios

RCP	Description
RCP2.6	Its radiative forcing level first reaches a value around 3.1 Wm^{-2} mid- century, returning to 2.6 Wm^{-2} by 2100. Under this scenario greenhouse gas (GHG) emissions and emissions of air pollutants are reduced substantially over time.
RCP4.5	It is a stabilization scenario where total radiative forcing is stabilized before 2100 by employing a range of technologies and strategies for reducing GHG emissions.
RCP6.0	It is a stabilization scenario where total radiative forcing is stabilized after 2100 without overshoot by employing a range of technologies and strategies for reducing GHG emissions.
RCP8.5	It is characterized by increasing GHG emissions over time representative of scenarios in the literature leading to high GHG concentration levels.

Climate change data projected by GCM's on daily basis is used for the present study. Daily data of following variables has taken

1. Rainfall
2. Maximum Temperature
3. Minimum Temperature
4. Solar radiation

The regional climate scenarios including radiation, Maximum temperature (T_{max}), Minimum temperature (T_{min}) and precipitation as inputs of the CERES-Rice model to simulate the impacts of climate change on rice yields in Kerala.

3.9. GENERAL CIRCULATION MODELS (GCM) USED

The Ensembled mean data of seventeen models has been used for the years 2030, 2050 and 2080.

Table 7. General Circulation Models used for the study

No	**Model**	**Institution**
1	BCC-CSM 1.1	Beijing Climate Center, China Meteorological Administration
2	BCC-CSM 1.1(m)	Beijing Climate Center, China Meteorological Administration
3	CSIRO-Mk3.6.0	Commonwealth Scientific and Industrial Research Organization and the Queensland Climate Change Centre of Excellence
4	FIO-ESM	The First Institute of Oceanography, SOA, China
5	GFDL-CM3	Geophysical Fluid Dynamics Laboratory
6	GFDL-ESM2G	Geophysical Fluid Dynamics Laboratory
7	GFDL-ESM2M	Geophysical Fluid Dynamics Laboratory
8	GISS-E2-H	NASA Goddard Institute for Space Studies
9	GISS-E2-R	NASA Goddard Institute for Space Studies
10	HadGEM2-ES	Met Office Hadley Centre
11	IPSL-CM5A-LR	Institute Pierre-Simon Laplace
12	IPSL-CM5A-MR	Institute Pierre-Simon Laplace
13	MIROC-ESM	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology
14	MIROC-ESM-CHEM	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology
15	MIROC5	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies
16	MRI-CGCM3	Meteorological Research Institute
17	NorESM1-M	Norwegian Climate Centre

The results of the experiment entitled "Crop weather modeling for Cocoa production in the humid tropics under the purview of climate change" are presented in this chapter. The effect of different weather parameters on growth and yield of Cocoa were studied. The Crop simulation model SUCROS-Cocoa developed by Wageningen University was validated and used for studying the impact of climate change based on IPCC projections for the year 2030 and 2050 under Representative Concentration Pathways 4.5 (RCP 4.5).

4.1 CLIMATE OF THE STATION

The daily weather parameters viz., maximum and minimum temperatures, rainfall, morning and afternoon relative humidity, wind speed and Bright sunshine hours recorded at Agro-meteorological observatory, College of Horticulture, Vellanikkara were used for the study. The general climate of the location has studied for 35 years (1983-2017). The different climate variables (monthly) of the location has presented in the Fig. 1-6.

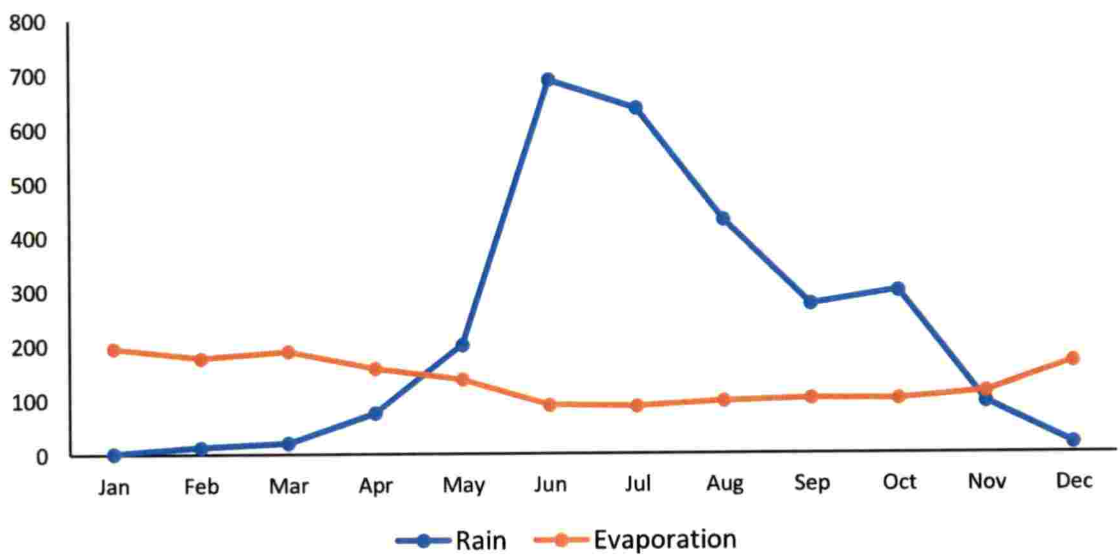

Fig.1. Rainfall and Evaporation

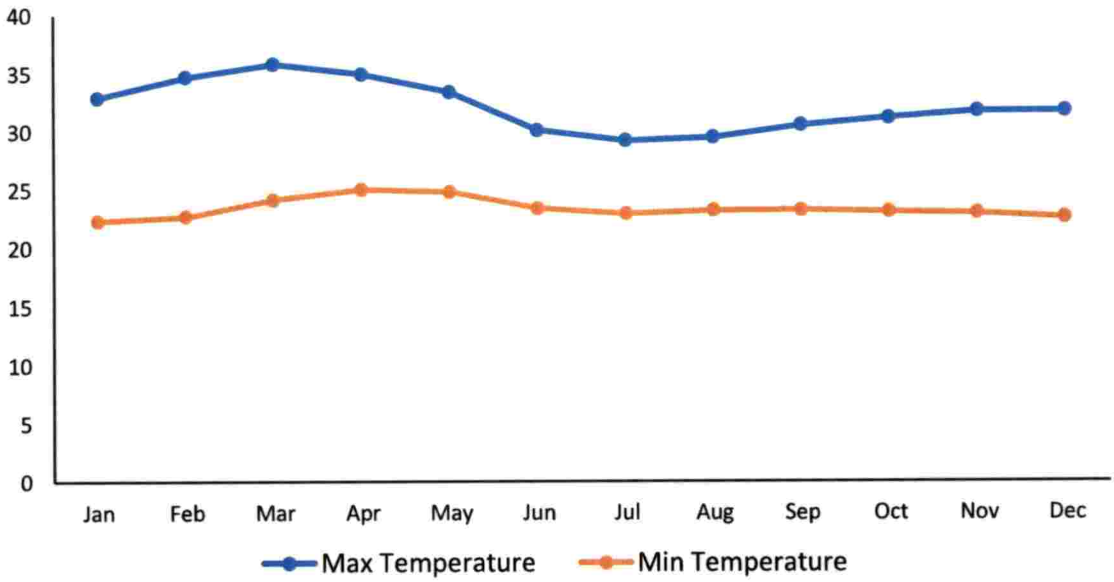

Fig.2. Maximum and minimum Temperature

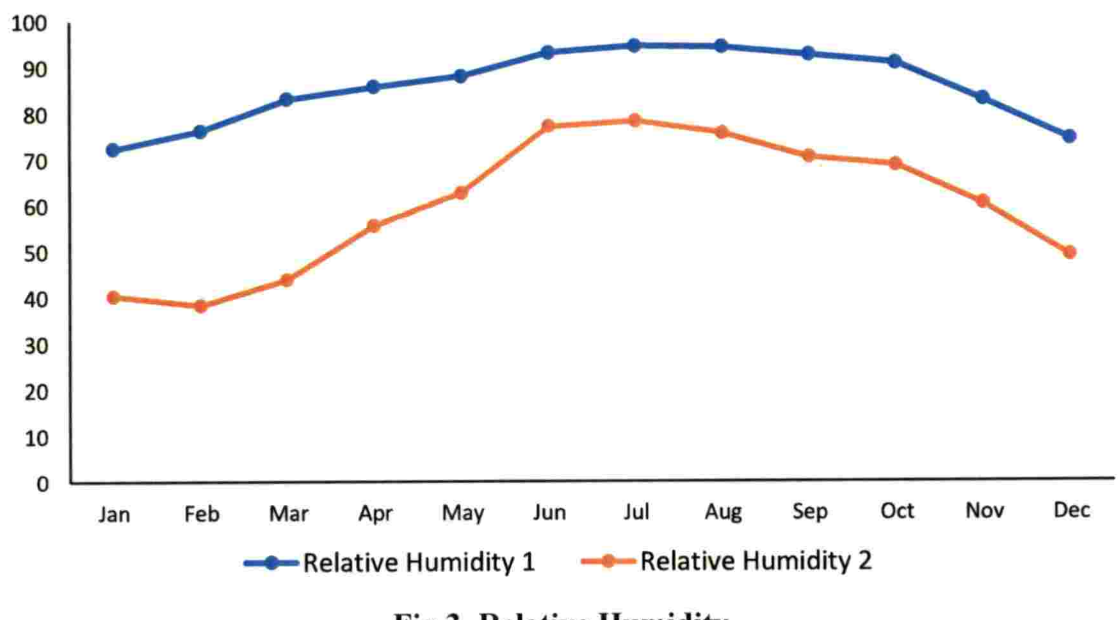

Fig.3. Relative Humidity

39

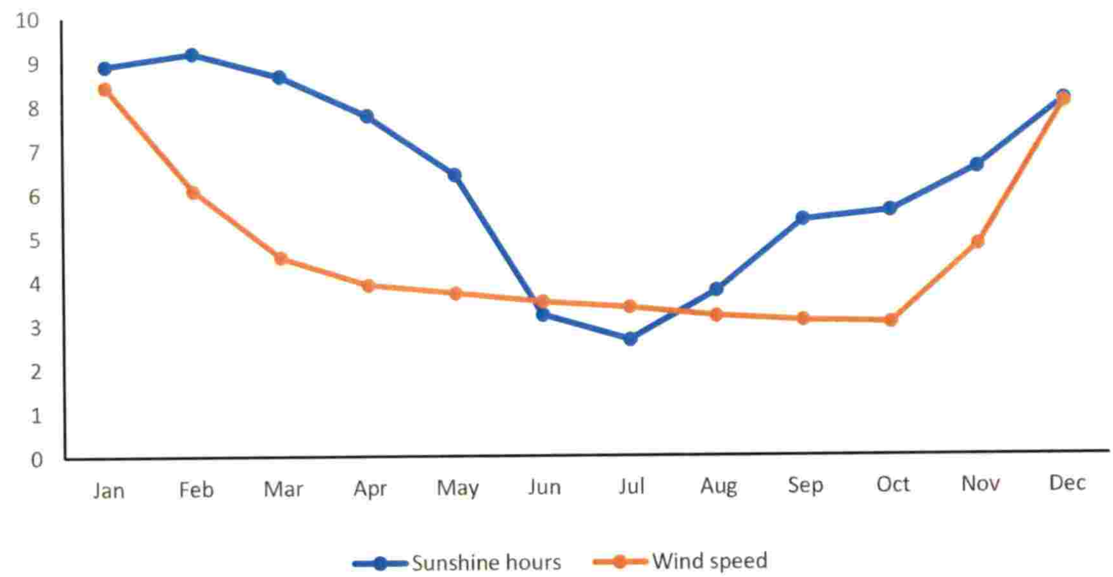

Fig.4. Solar radiation and Wind speed

4.2. WEATHER DURING THE CROP PERIOD

The daily weather parameters viz., maximum and minimum temperatures, rainfall, morning and afternoon relative humidity, wind speed and Bright sunshine hours recorded at Agro-meteorological observatory, College of Horticulture, Vellanikkara, Thrissur were used for the study and the weekly mean of the weather variables are depicted in Table 8.

The highest monthly temperature recorded during the months of February, March and April. December and January are considered as the coldest months. Maximum morning Relative humidity was more than 90% during the months from June to October and the lowest morning Relative humidity was recorded in the months of December and January. The afternoon Relative humidity also followed the same trend. Highest monthly average wind speed was recorded in the months of December and January. The period from June to October is considered as the rainy season which contributed more than 85% of the total annual rainfall. The average annual evaporation is 1394.7 mm and the average monthly evaporation is 116 mm.

Table 8. Weather during the experiment Period

Weather	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
RF	2012	0.0	0.0	3.5	101.9	117.3	551.5	375.8	616.5	191.8	145.6	46.7	19.8
	2013	0.0	84.4	14.6	0.0	99.1	1031.8	932.3	305.9	344.1	369.8	82.0	0.5
	2014	0.0	0.0	0.0	61.0	323.6	469.8	768.0	599.8	215.1	224.6	85.3	9.6
EVP	2012	180.1	160.3	176.4	139.6	123.6	83.1	75.1	77.9	90.4	109.1	114.2	151.1
	2013	158.2	168.8	156.7	131.8	111.7	78.4	80.9	71.1	79.4	103.8	100.7	157.4
	2014	152.5	142.4	152.3	134.6	111.8	68.7	80.1	84.9	72.7	81.8	91.9	130.7
SS	2012	294.0	265.4	234.7	199.2	185.5	84.1	99.5	90.7	137.4	192.1	224.9	252.4
	2013	270.9	241.4	221.2	194.9	124.1	29.4	23.8	134.3	110.3	163.2	187.2	254.7
	2014	277.6	240.8	264.2	192.4	182.0	90.1	49.3	81.3	172.6	135.2	151.9	188.5
MAX T	2012	32.8	35.1	35.2	34.7	32.6	30.1	30.0	29.2	30.4	32.1	32.5	33.0
	2013	34.1	34.7	35.4	34.9	33.6	28.5	28.4	29.9	30.0	30.8	32.6	31.9
	2014	32.9	34.7	36.7	35.3	33.2	30.9	29.5	29.5	31.3	31.9	31.6	31.9
Min T	2012	21.3	22.1	24.2	24.8	25.3	23.9	23.7	23.0	23.3	23.5	22.7	23.2
	2013	22.3	23.3	24.4	25.1	25.2	22.7	22.7	22.9	22.2	22.6	23.9	22.3
	2014	23.0	22.9	24.2	25.7	25.0	24.4	23.1	23.2	23.3	23.7	23.2	23.2
RH1	2012	75	75	86	89	88	95	95	95	94	90	85	73
	2013	70	76	82	88	92	97	97	96	95	96	87	77
	2014	66	75	76	89	90	95	95	97	95	93	84	78
RH2	2012	40	33	49	57	64	74	74	77	71	64	53	43
	2013	34	37	46	55	61	83	84	72	75	70	60	45
	2014	36	37	34	57	64	76	80	76	69	68	60	53
WS	2012	6.3	5.4	3.5	3.4	3.0	2.7	2.9	2.5	2.3	3.1	3.0	6.7
	2013	5.2	6.1	4.5	3.6	2.6	1.6	1.9	2.1	1.7	1.7	3.0	5.5
	2014	6.7	4.5	3.8	2.3	2.5	2.2	2.1	1.9	2.2	2.2	3.7	5.4

4.2 BIOMETRIC OBSERVATIONS

4.2.1 Number of cherelle per tree

The effect of weather parameters on number Cherelle of plant was not significant. But it can be seen from the table 9. that the Cherelle production was more during monsoon season.

Table 9. Pod, Cherelle, Harvest characteristics of cocoa

Treatments	Pods per plant	Cherelle per plant	Number of harvests
2012 summer	22.3	14.7	12.0
2012 Monsoon	21.7	15.7	15.7
2012 Post monsoon	19.0	11.7	10.7
2013 summer	27.3	13.7	12.0
2013 Monsoon	19.7	14.7	13.0
2013 Post monsoon	22.3	11.3	15.7
2014 summer	20.7	14.7	11.3
2014 Monsoon	23.0	14.3	14.0
2014 Post monsoon	25.0	18.6	11.7
CV	34.671	29.014	19.245
CD	NS	NS	NS

4.2.2. Number of pods harvested per month

The number of pods per plant during the three major seasons depicted in table no 9. It can be informed from the table that the effect of weather on number of pods per plant was not significant. Even though the height number of pods were recorded mainly during summer season

4.2.3. Number of Harvests

The number of harvests per season was recorded and shown in table 9. though the effect of weather on number of harvests was merge the monsoon season showed high number of harvests.

4.2.4. Floral characteristics

The effect of weather on floral characteristics of cocoa is presented in table 10. Among the floral characteristics only staminode length differ significantly. Other parameters like stamen length, length of gynoecium and style length did not differ significantly. The staminode length was more during the year 2012 followed by 2013 and then 2014. It is interesting to notice that the gynaecium was more during summer season.

Table 10. Floral characteristics of cocoa

Treatments	Staminode length (cm)	Stamen length (cm)	Length of gynoecium (cm)	Style length (cm)
2012 summer	0.7	0.2	0.4	0.3
2012 Monsoon	0.7	0.2	0.3	0.2
2012 Post monsoon	0.6	0.2	0.2	0.3
2013 summer	0.6	0.2	0.4	0.3
2013 Monsoon	0.6	0.2	0.3	0.2
2013 Post monsoon	0.6	0.2	0.2	0.3
2014 summer	0.6	0.2	0.4	0.3
2014 Monsoon	0.5	0.2	0.3	0.2
2014 Post monsoon	0.5	0.2	0.2	0.3
CV	6.514	NS	NS	NS
CD	0.068	NS	NS	NS

4.3. POD AND BEAN CHARACTERS

4.3.1. Pod characters

Pod and bean characters like pod length, width, weight, wet bean weight, husk weight and weight of a single dry bean are given in the Table. 11. The pods harvested during November (post monsoon season) was superior in pod weight. In contrast, the pods harvested during monsoon were inferior in pod weight. The seasonal variations were found significant. In the case of wet weight, it can be observed that seasonal impact of weather was insignificant. The wet weight of pods was superior in year 2014 followed by 2012 and then 2013. Similar trend was observed in the case of pod length, pod breadth and husk weight.

Table 11. Effect of weather on Pod characters

Year	Season	Pod weight	Wet weight	Pod length	Husk weight	Pod breadth
2012	summer	260^{d}	94.020^{c}	12.32^{b}	7.540^{bc}	6.54^{c}
	monsoon	188^{f}	80.06^{d}	11.34^{c}	7.460^{cd}	6.30^{c}
	post monsoon	562^{b}	82.60^{d}	11^{c}	7.140^{d}	6.30^{c}
2013	summer	250^{de}	63.20^{e}	9.16^{d}	5.52^{e}	6.24^{c}
	monsoon	192^{f}	59.94^{e}	9.28^{d}	5.72^{e}	5.24^{d}
	post monsoon	558^{b}	63.80^{e}	9.42^{d}	5.70^{e}	6.38^{c}
2014	summer	302^{c}	164.10^{a}	15.76^{a}	8.58^{a}	9.82^{b}
	monsoon	210^{ef}	154.30^{b}	15.76^{a}	8.86^{a}	10.60^{a}
	post monsoon	626^{a}	157.10^{ab}	15.16^{a}	7.86^{b}	9.64^{b}
CV		9.293	7.015	4.783	3.716	6.605

4.3.2. Bean characters

The effect of weather on bean characters are given in Table 12. It can be observed that the number of beans were more during the year 2014 followed by 2012. The least number of beans per pod were observed in year 2013. Whereas, the number of flat beans were less in year 2014 and 2012. The greater number of flat beans were observed during 2013. The total soluble sugar was observed high during the year 2012 followed by 2014.

Table 12. Effect of weather on bean characters

Year	Season	No. of beans	No. of flat beans	TSS
2012	summer	38.40^{cd}	0.80^{bc}	22.20^{a}
	monsoon	39.60^{bc}	0.60^{bc}	22^{a}
	post monsoon	38.30^{cd}	1.80^{b}	21.40^{a}
2013	summer	33.40^{ef}	3.80^{a}	16.20^{d}
	monsoon	31.06^{f}	4.20^{a}	17.40^{cd}
	post monsoon	35.40^{de}	3.60^{a}	17.40^{cd}
2014	summer	43.40^{a}	0.40^{c}	19.80^{b}
	monsoon	40.80^{abc}	0.70^{bc}	18.80^{bc}
	post monsoon	42.08^{ab}	1^{bc}	19^{b}
CV		6.837	54.732	6.212

4.4 CROP WEATHER RELATIONSHIPS

Simple linear correlations between important morphological, yield attributes and mean weekly weather parameters like maximum temperature, minimum temperature, mean temperature and temperature range, relative humidity (morning, afternoon, mean and difference between morning and afternoon relative humidity), wind speed, bright sunshine, were carried out.

4.4.1 Weather and pod weight of Cocoa

Correlation between pod weight and different weather parameters has found out and presented in the Table 13. Pod weight had a significant positive correlation with morning relative humidity, afternoon relative humidity and rainfall, whereas maximum temperature, sunshine hours and evaporation showed a significant negative correlation. The minimum temperature showed positive correlation the beginning of pod formation and it was negatively influenced the pod weight during the final stages of pod development. Soil temperature at different depths were also negatively influenced the pod development.

4.4.2. Weather and Number of Beans per Pod

Correlation between different weather parameters and number of beans per pod was done and presented in the Table 14. There was significant negative correlation with maximum temperature, solar radiation, soil temperature and evaporation during the initial stages of pod development but during the final stages of pod development these weather parameters had significant positive correlation. The influence of relative humidity, rainfall, rainy days and wind speed just opposite compared to temperature and evaporation. They had a positive correlation in the initial stages of pod development and negative correlation during the final stages. Increase in minimum temperature during the initial as well as final stages of pod development were detrimental number of beans per pod where as it has a positive influence during the middle stages.

4.4.3. Weather and Total Soluble Sugar

Correlation between TSS and different weather parameters has found out and presented in the Table 15. TSS had a significant positive correlation with maximum temperature, minimum temperature, sunshine hours, soil temperatures, and evaporation during the final stages of pod development whereas the minimum temperature, morning soil temperature and evaporation during the initial stages had a negative correlation. Weather parameters like relative humidity, wind speed, rainfall and rainy days had negative correlation with TSS during the fag end of the pod development.

Table13. Weather and Pod Weight of Cocoa

Week	Max T	Min T	STM 5	STM 10	STM 20	STE 5	STE 10	STE 20	RH1	RH2	WS	SS	RF	RD	EVP
1	NS	0.805**	0.828**	0.847**	0.812**	NS	NS	0.351*	0.336*	0.444*	0.444*	-0.738**	NS	-0.386*	NS
2	NS	0.671**	0.768**	0.786**	0.681**	NS	NS	0.397*	0.362*	NS	NS	-0.624**	NS	-0.532**	NS
3	NS	0.432*	0.791**	0.849**	0.826**	0.416*	NS	0.395*	0.367*	NS	NS	NS	-0.582**	-0.374*	NS
4	NS	0.574**	0.646**	0.626**	0.595**	NS	NS	NS	0.475**	0.397*	0.397*	-0.508**	-0.486**	-0.538**	NS
5	-0.53**	NS	NS	NS	NS	-0.417*	-0.41*	-0.401*	0.538**	0.568**	0.568**	-0.564**	NS	NS	NS
6	-0.65**	NS	NS	NS	NS	-0.583**	-0.582**	-0.597**	0.611**	0.679**	0.679**	-0.846**	0.793**	0.653**	NS
7	-0.66**	NS	NS	NS	NS	-0.555**	-0.582**	-0.554**	0.526**	0.774**	0.774**	-0.804**	0.804**	0.805**	-0.691**
8	-0.7**	NS	NS	-0.372*	-0.407*	-0.604**	-0.635**	-0.622**	0.429*	0.748**	0.748**	-0.776**	0.873**	0.842**	-0.527**
9	-0.74**	NS	NS	NS	-0.336*	-0.616**	-0.591**	-0.554**	0.522**	0.776**	0.776**	-0.659**	0.81**	0.514**	NS
10	-0.72**	NS	NS	NS	-0.349*	-0.67**	-0.653**	-0.64**	0.561**	0.85**	0.85**	-0.815**	0.746**	0.767**	-0.39*
11	-0.69**	NS	NS	NS	-0.366*	-0.687**	-0.682**	-0.643**	0.604**	0.86**	0.86**	-0.852**	0.625**	0.837**	-0.405*
12	-0.75**	NS	NS	-0.455**	-0.469**	-0.802**	-0.738**	-0.719**	0.687**	0.901**	0.901**	-0.899**	0.885**	0.876**	-0.71**
13	-0.76**	NS	NS	-0.455**	-0.505**	-0.773**	-0.696**	-0.745**	0.681**	0.854**	0.854**	-0.714**	0.764**	0.866**	-0.376*
14	-0.79**	NS	NS	NS	NS	-0.801**	-0.727**	-0.578**	0.679**	0.819**	0.819**	-0.794**	0.628**	0.813**	-0.592**
15	-0.72**	NS	NS	-0.427*	-0.454**	-0.741**	-0.721**	-0.705**	0.701**	0.785**	0.785**	-0.633**	0.442*	0.838**	-0.806**
16	-0.8**	NS	NS	NS	-0.338*	-0.838**	-0.754**	-0.589**	0.74**	0.744**	0.744**	-0.688**	0.552**	0.345*	-0.753**
17	-0.52**	NS	NS	NS	NS	-0.481**	-0.544**	NS	0.642**	0.546**	0.546**	NS	NS	0.82**	-0.635**
18	-0.4*	NS	NS	NS	NS	NS	NS	NS	0.642**	0.55**	0.55**	-0.474**	NS	0.785**	-0.645**
19	-0.59**	NS	NS	-0.403*	-0.402*	-0.504**	-0.505**	-0.48**	0.642**	0.555**	0.555**	-0.453**	NS	0.389*	-0.639**
20	-0.59**	NS	-0.527**	-0.588**	-0.544**	-0.556**	-0.518**	-0.516**	0.496**	0.57**	0.57**	-0.464**	NS	NS	-0.447*
21	-0.53**	NS	NS	-0.367*	-0.419*	-0.401*	-0.4*	-0.362*	0.638**	0.534**	0.534**	NS	NS	NS	-0.678**
22	-0.39*	-0.343*	-0.417*	-0.497**	-0.497**	NS	NS	NS	0.524**	NS	NS	NS	NS	0.535**	-0.444*
23	NS	-0.554**	-0.608**	-0.565**	-0.542**	NS	NS	NS	0.515**	NS	NS	NS	NS	NS	-0.389*
24	-0.35*	NS	NS	-0.408*	-0.433*	-0.407*	NS	NS	0.558**	0.405*	0.405*	NS	NS	NS	-0.561**
25	-0.52**	-0.372*	-0.59**	-0.575**	-0.572**	-0.593**	-0.553**	-0.51**	0.431*	0.496**	0.496**	-0.411*	NS	NS	-0.491**
26	-0.38*	-0.503**	-0.627**	-0.59**	-0.604**	-0.521**	-0.503**	-0.493**	NS	0.351*	0.351*	NS	NS	NS	-0.6**
27	NS	-0.341*	-0.562**	-0.55**	-0.563**	-0.561**	-0.511**	-0.432*	NS	NS	NS	NS	NS	NS	-0.577**

Table 14. Weather and Number of Beans per Pod

Week	Max T	Min T	STM 5	STM10	STM20	STE 5	STE 10	STE 20	RH1	RH2	WS	SS	RF	RD	EVP
1	-0.64**	0.39*	NS	NS	NS	-0.65**	NS	NS	NS	0.71**	0.71**	-0.52**	0.39*	0.36*	-0.65**
2	-0.54**	0.43*	NS	NS	NS	-0.40*	NS	NS	NS	0.63**	0.63**	-0.35*	NS	0.34*	-0.50**
3	-0.52**	0.60**	0.39*	0.33*	NS	NS	NS	NS	0.35*	0.71**	0.71**	-0.48**	0.34*	0.36*	-0.69**
4	-0.7**	0.69**	NS	NS	NS	-0.57**	NS	NS	0.43*	0.76**	0.76**	-0.72**	NS	NS	-0.8**
5	-0.56**	NS	NS	-0.45**	-0.54**	-0.62**	-0.39*	-0.48**	NS	0.52**	0.52**	NS	NS	0.64**	-0.70**
6	-0.71**	NS	-0.37*	-0.67**	-0.71**	-0.74**	-0.51**	-0.64**	NS	0.58**	0.58**	-0.60**	0.61**	0.75**	-0.80**
7	-0.74**	-0.51**	-0.54**	-0.68**	-0.74**	-0.76**	-0.61**	-0.70**	NS	0.62**	0.62**	-0.62**	0.50**	0.60**	-0.79**
8	-0.67**	-0.71**	-0.64**	-0.81**	-0.82**	-0.74**	-0.62**	-0.69**	NS	0.60**	0.60**	-0.61**	0.56**	0.61**	-0.84**
9	-0.67**	-0.60**	-0.60**	-0.74**	-0.75**	-0.71**	-0.55**	-0.59**	NS	0.33*	0.33*	-0.35*	0.65**	0.63**	-0.74**
10	-0.71**	-0.79**	-0.67**	-0.82**	-0.82**	-0.71**	-0.56**	-0.71**	NS	0.47**	0.47**	-0.41*	NS	0.64**	NS
11	-0.71**	-0.68**	-0.73**	-0.85**	-0.86**	-0.77**	-0.63**	-0.74**	NS	0.49**	0.49**	-0.51**	0.37*	0.45**	NS
12	-0.67**	-0.50**	-0.60**	-0.71**	-0.71**	-0.62**	-0.50**	-0.63**	NS	NS	NS	NS	NS	NS	NS
13	-0.61**	-0.71**	-0.68**	-0.79**	-0.78**	-0.53**	-0.45**	-0.58**	NS	NS	NS	NS	0.35*	0.56**	NS
14	-0.52**	-0.67**	-0.73**	-0.75**	-0.76**	-0.59**	-0.67**	-0.70**	NS	NS	NS	NS	NS	0.41*	NS
15	-0.71**	-0.83**	-0.88**	-0.89**	-0.88**	-0.70**	-0.76**	-0.75**	NS	NS	NS	-0.53**	0.52**	0.56**	-0.34*
16	-0.51**	-0.45**	-0.63**	-0.67**	-0.69**	-0.38*	-0.59**	-0.58**	NS	NS	NS	NS	0.43*	0.34*	NS
17	NS	-0.34*	NS	-0.33*	NS	NS	NS	NS	NS	NS	NS	0.36*	-0.40*	NS	NS
18	NS	-0.46**	-0.48**	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
19	NS	-0.34*	NS	NS	NS	0.36*	0.33*	NS	NS	-0.34*	-0.34*	0.39*	-0.66**	-0.37*	NS
20	0.34*	NS	0.34*	0.34*	0.34*	0.40*	0.43*	0.45**	NS	-0.35*	-0.35*	0.39*	-0.74**	-0.62**	NS
21	0.44*	NS	0.37*	0.42*	0.39*	0.53**	0.53**	0.52**	-0.34*	-0.37*	-0.37*	0.74**	-0.78**	-0.71**	NS
22	0.55**	NS	NS	0.43*	0.41*	0.63**	0.65**	0.66**	NS	-0.60**	-0.60**	0.71**	-0.55**	-0.45**	NS
23	0.65**	NS	NS	0.37*	0.4*	0.53**	0.58**	0.56**	-0.36*	-0.72**	-0.72**	0.78**	-0.52**	-0.57**	NS
24	0.6**	NS	0.44*	0.44*	0.45**	0.43*	0.52**	0.54**	NS	-0.41*	-0.41*	0.69**	-0.69**	-0.37*	0.34*
25	0.46**	0.36*	NS	0.34*	0.33*	NS	0.33*	0.37*	-0.40*	-0.49**	-0.49**	0.48**	-0.44*	-0.60**	0.45**
26	0.52**	0.41*	NS	NS	NS	0.35*	0.34*	0.36*	-0.55**	-0.55**	-0.55**	0.66**	-0.59**	-0.50**	NS
27	0.47**	0.33*	0.345*	0.35*	0.35*	NS	NS	0.42*	-0.5**	-0.52**	-0.52**	0.34*	-0.39*	-0.71**	0.39*

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Table 15. Weather and TSS of Cocoa

Week	Max t	Min t	STM 5	STM10	STM20	STE 5	STE 10	STE 20	RH1	RH2	WS	SS	RF	RD	EVP
1	-0.57**	NS	-0.42*	-0.4*	-0.39*	-0.51**	NS	NS	NS	NS	NS	NS	NS	0.34*	-0.65**
2	NS	NS	-0.47**	-0.46**	-0.50**	NS	NS	NS	-0.35*	NS	NS	NS	NS	0.63**	-0.40*
3	-0.47**	NS	NS	NS	NS	-0.36*	NS	NS	NS	0.41*	0.41*	NS	0.67**	0.75**	-0.81**
4	-0.4*	NS	-0.37*	NS	NS	-0.40*	NS	NS	NS	NS	NS	NS	0.58**	0.57**	-0.72**
5	NS	NS	-0.67**	-0.55**	-0.55**	NS	NS	NS	-0.34*	NS	NS	NS	0.36*	0.79**	-0.79**
6	NS	NS	-0.71**	-0.54**	-0.53**	NS	NS	NS	-0.33*	NS	NS	NS	NS	0.38*	-0.62**
7	NS	-0.60**	-0.75**	-0.52**	-0.51**	NS	NS	NS	-0.50**	NS	NS	NS	NS	NS	NS
8	NS	-0.64**	-0.81**	-0.56**	-0.54**	NS	NS	NS	-0.39*	NS	NS	NS	NS	NS	-0.47**
9	NS	-0.59**	-0.8**	-0.53**	-0.52**	NS	NS	NS	-0.57**	NS	NS	NS	NS	0.37*	-0.76**
10	NS	-0.61**	-0.83**	-0.50**	-0.46**	NS	NS	NS	-0.56**	NS	NS	NS	NS	NS	NS
11	NS	-0.65**	-0.84**	-0.58**	-0.55**	NS	NS	NS	-0.50**	NS	NS	NS	NS	NS	NS
12	NS	-0.41*	-0.70**	-0.38*	-0.39*	NS	NS	NS	-0.65**	-0.36*	-0.36*	0.42*	NS	NS	0.52**
13	NS	-0.51**	-0.75**	-0.41*	-0.37*	NS	NS	NS	-0.60**	-0.46**	-0.46**	0.45**	NS	NS	0.52**
14	NS	-0.80**	-0.66**	-0.56**	-0.60**	NS	NS	-0.46**	-0.36*	-0.42*	-0.42*	0.41*	NS	NS	0.58**
15	NS	-0.82**	-0.72**	-0.63**	-0.62**	NS	NS	-0.40*	-0.44*	-0.33*	-0.33*	NS	NS	NS	NS
16	NS	-0.81**	-0.78**	-0.65**	-0.66**	NS	NS	-0.44*	-0.58**	-0.56**	-0.56**	0.67**	NS	NS	0.47**
17	NS	-0.73**	-0.55**	-0.43*	-0.37*	0.56**	NS	NS	-0.62**	-0.64**	-0.64**	0.64**	-0.43*	-0.36*	0.61**
18	0.42*	-0.70**	-0.57**	NS	NS	0.44*	NS	NS	-0.67**	-0.66**	-0.66**	0.60**	-0.35*	-0.57**	0.51**
19	0.7**	NS	NS	0.35*	0.47**	0.73**	0.69**	0.58**	-0.63**	-0.69**	-0.69**	0.72**	-0.69**	-0.72**	0.69**
20	0.77**	NS	0.58**	0.70**	0.67**	0.81**	0.78**	0.71**	-0.68**	-0.80**	-0.80**	0.75**	-0.81**	-0.79**	0.67**
21	0.82**	-0.37*	NS	0.43*	0.43*	0.76**	0.72**	0.54**	-0.75**	-0.82**	-0.82**	0.87**	-0.86**	-0.71**	0.73**
22	0.82**	NS	NS	0.58**	0.57**	0.81**	0.77**	0.70**	-0.68**	-0.85**	-0.85**	0.86**	-0.47**	-0.83**	0.53**
23	0.83**	0.45**	0.71**	0.75**	0.73**	0.78**	0.79**	0.73**	-0.56**	-0.81**	-0.81**	0.69**	-0.54**	-0.76**	NS
24	0.82**	0.37*	0.77**	0.80**	0.8**	0.74**	0.79**	0.77**	-0.55**	-0.63**	-0.63**	0.74**	-0.69**	-0.63**	0.65**
25	0.77**	0.58**	0.71**	0.74**	0.72**	0.71**	0.71**	0.73**	-0.70**	-0.80**	-0.80**	0.79**	-0.65**	-0.73**	0.81**
26	0.78**	0.78**	0.70**	0.70**	0.70**	0.72**	0.69**	0.69**	-0.70**	-0.75**	-0.75**	0.73**	-0.61**	-0.65**	0.67**
27	0.74**	0.55**	0.66**	0.68**	0.7**	0.66**	0.69**	0.71**	-0.55**	-0.83**	-0.83**	0.67**	-0.60**	-0.81**	0.79**

4.5 MULTIPLE REGRESSION MODELS DEVELOPED

Stepwise regression analysis was carried out to select the critical variables, which contributed to pod weight, number of beans and total soluble sugar.

Among all the weather parameters minimum temperature has greatest influence in determining the yield and yield attributes in both the varieties. Multiple regression equations were developed based on minimum temperature for estimation of grain yield.

4.5.1 Pod Weight

Pod Weight = 572.554 + 6.324 $RH_2 12$ – 25.824 TMin 9-1.214 RF_1 (R2 - 0.97)

Where,

RH = Relative humidity during 12^{th} week (%)

T min= Minimum temperature during 9^{th} week (°C)

RF- Rainfall during the first week (mm)

4.5.2 Total Soluble Sugar

TSS = 27.994 + 0.557 SH21 – 0.528 TMin 17 (R2 - 0.97)

Where,

SS =Bright sunshine hours (hr)

T min= Minimum temperature during 17^{th} week (°C)

4.6 SUCROS Cocoa MODEL VALIDATION

The yield and biometric parameters recorded at Cocoa Research Station, Vellanikkara was used for estimating various model parameters. Simulations in SUCROS-Cocoa was carried out for cacao trees of 1–11-year-old. Furthermore, the densities of model trees is bounded to 700–2500 ha-1. Climatic limitations of the model are an average day temperature between 10 and 40°C, and an annual precipitation of at least 1250 mm per year. The leaf area index (LAI) of shade trees should not exceed 3, and soil depth should be >1.5 m. The biomass partitioning of cocoa used for the model is presented in table16 and the observed and simulated yields of cocoa were presented in table 17. It can be seen from the table 17 and figure 6 that the yield prediction done by the model was reasonably good and able to pickup the variations in weather parameters on pod production. Hence, it can be inferred that SUCROS Cocoa can be used for forecasting the cocoa yield.

Table 16. Biomass partitioning of cocoa (kg DW ha-1)

	WTOT	WRT	WPD	WLV	WWD
Year 1	31281	5824.5	1351.8	4977.2	19127
Year 2	37859	6883.3	1538.9	5941.2	23495
Year 3	39105	7163.7	1451.4	6007.7	24482
Year 4	40270	7344.1	1468.3	6121.4	25336
Year 5	40511	7383.7	1384.7	6071.1	25671
Year 6	41058	7420.7	1524.8	6336.1	25776
Year 7	41078	7467.5	1420.3	6195	25995
Year 8	42170	7605.9	1559.6	6487.3	26517
Year 9	42548	7740.3	1439.9	6398.3	26969
Year 10	43768	7853	1679.8	6867.5	27368
Year 11	44095	7965.9	1580.1	6706.7	27842

WTOT-Total dry biomass in kg per hectare, WRT-Root biomass in kg per hectare, WPD-Pod biomass in kg per hectare, WLV-Leaves biomass in kg per hectare, WWD-Wood biomass in kg per hectare

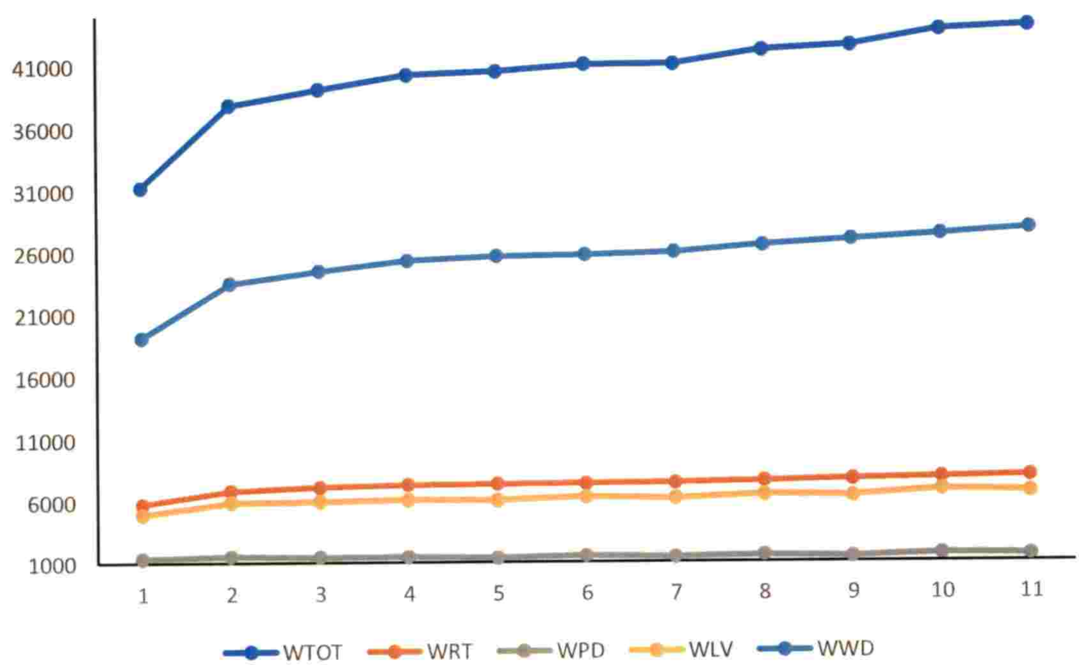

Fig. 5. Biomass partitioning of cocoa (kg DW ha-1)

Table 17. Observed and Predicted yield of cocoa (kg ha-1)

Year	Observed	Predicted
1997	3500	4238.2
1998	5800	5763.5
1999	3500	6071.0
2000	4000	6008.7
2001	4100	5964.7
2002	5109	6136.1
2003	5870	6234.8
2004	5900	6237.0
2005	5400	6254.2
2006	5800	6399.8
2007	6000	6533.9

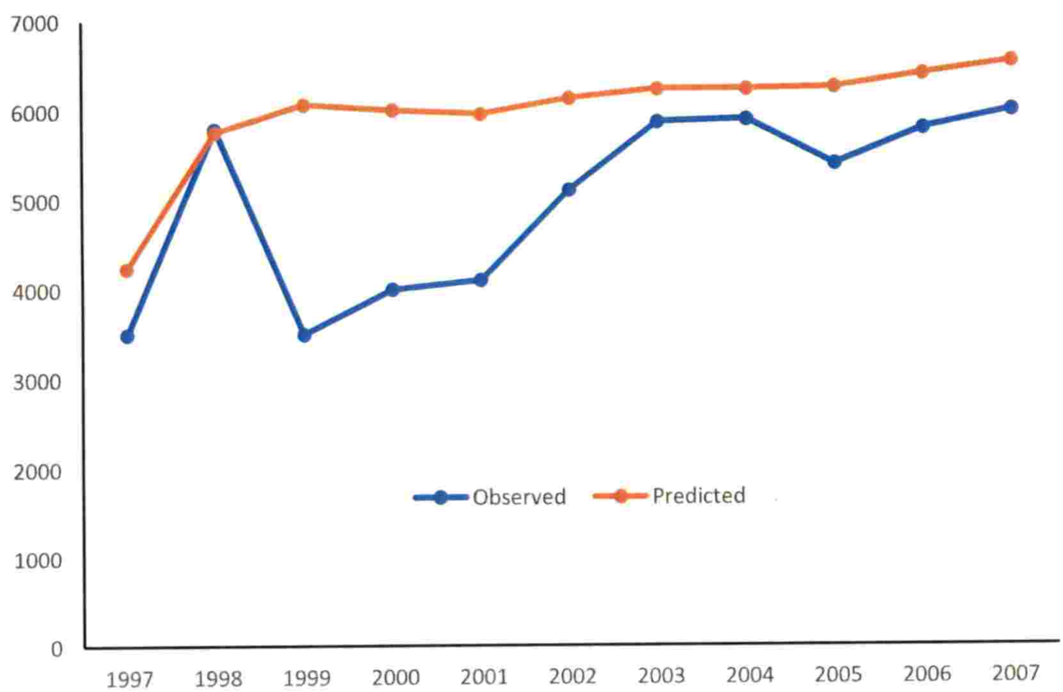

Fig 6. Observed and Predicted yield of cocoa (kg ha-1)

4.7 CLIMATE CHANGE IMPACT ON COCOA PRODUCTION

The future climatic projections have taken from Ensemble of 17 General Circulation Models (GCMs). The future carbon dioxide concentrations and climate data has been incorporated into crop simulation model and predicted the future yield for the years 2030, 2050 and 2080. The data on future climate as per RCP 4.5 projection is presented in figure 8 to 10. The climate data for the years 2030, 2050 and 2080 under RCP 4.5 has been presented in the Figures 7 and table 18.

As per the projections based on RCP 4.5, there will be considerable reduction in cocoa production during 2030s and 2050s whereas the yield will recuperate during 2080s. The yield will be reduced by 24 per cent, 10 per cent for the periods 2030s, and 2050s respectively (Table 18) but in 2080s the yield will be improved by 10 percent.

Table 18. Climate change impact on cocoa production

Present	2030	2050	2080
6533.9	4956	5818	7234

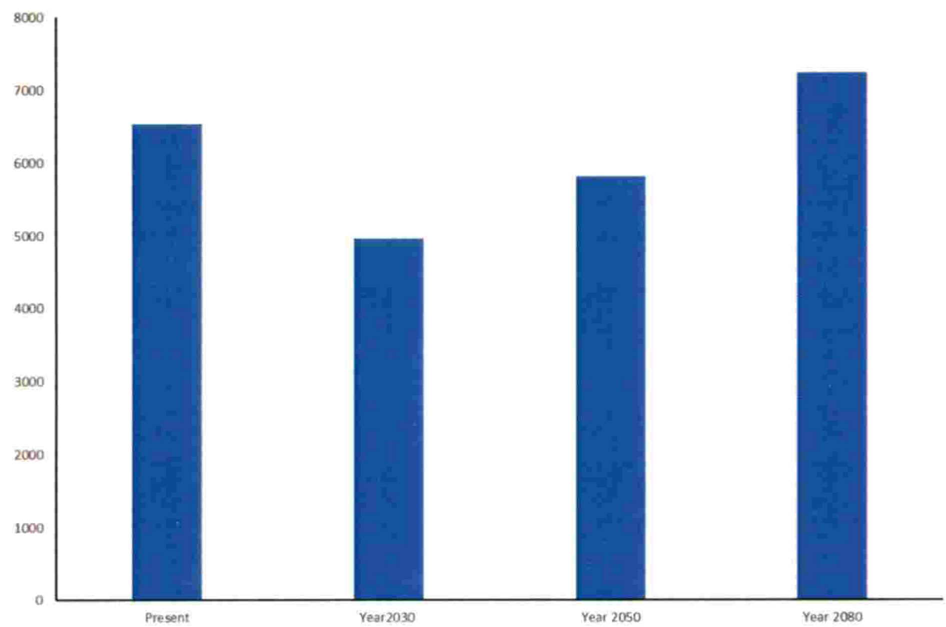

Fig 7. Climate Change impact of Cocoa Production

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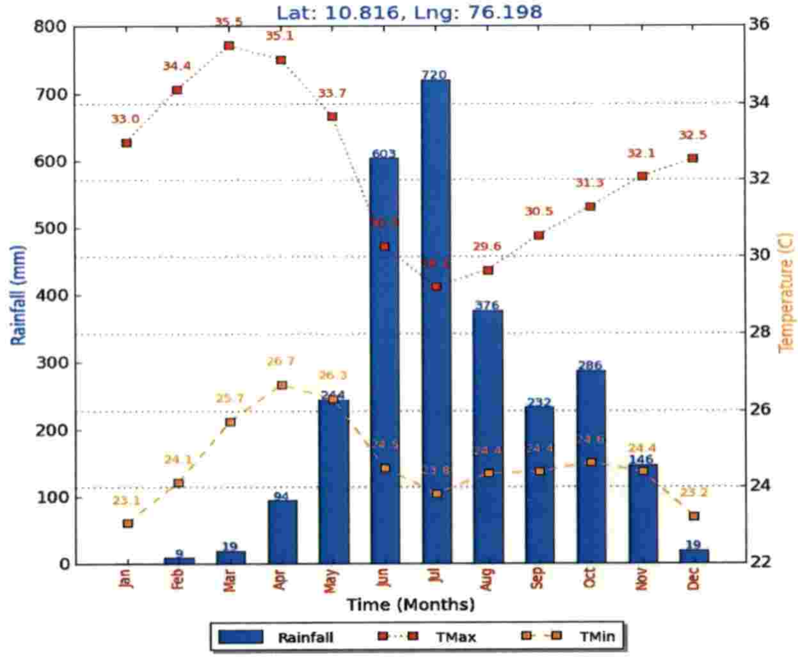

Fig 8. Climate of Thrissur in 2030s under RCP 4.5

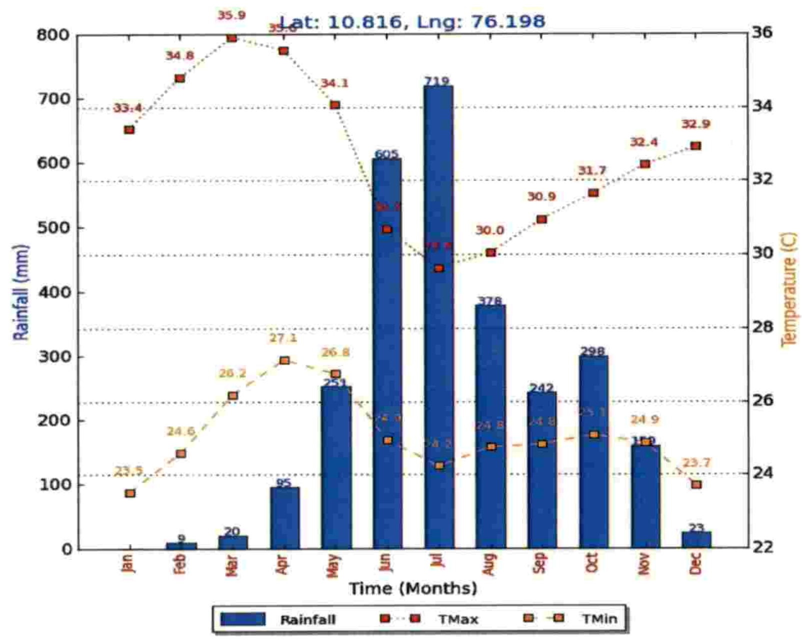

Fig 9. Climate of Thrissur in 2050s under RCP 4.5

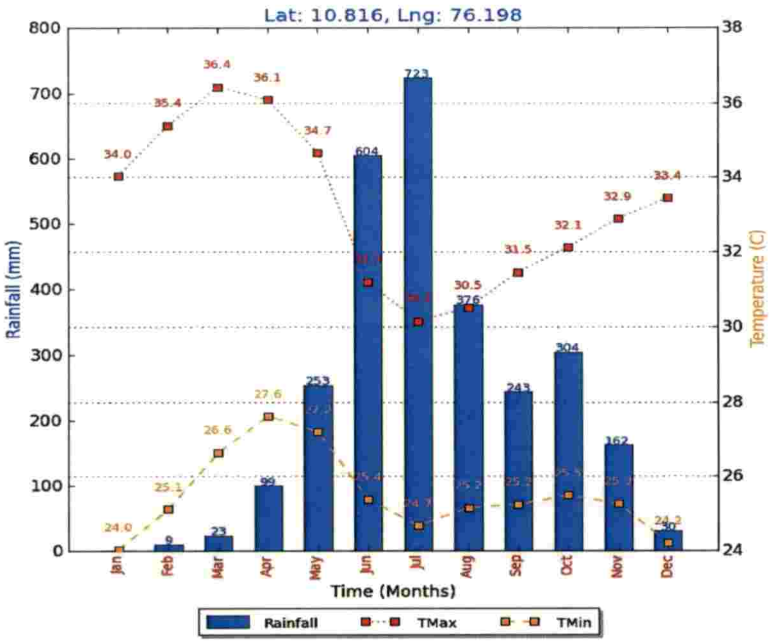

Fig 10. Climate of Thrissur in 2080s under RCP 4.5

4.8. CONCLUSIONS

- In the cocoa-growing regions of Kerala, the yearly and monthly minimum and maximum temperatures will increase by 2030 and will continue to increase progressively by 2050 (up to 2.0°C).
- The consequences of climate change are that the suitability within the current cocoa-growing areas will decrease seriously by 2050.
- The increase of the maximum temperature of the warmest month and annual temperature range will negatively impact cocoa production by 2050. These changes in temperature will also increase evapotranspiration of cocoa trees.

Chapter 5. Summary and conclusion

The present investigation on "Crop weather modeling for Cocoa production in the humid tropics under the purview of climate change" was undertaken at the Academy of Climate Change Education and Research Vellanikkara, to validate the SUCROS Cocoa model and to study the impact of climate change on Cocoa production by the periods 2030s 2050s and 2080s under RDP 4.5. The salient results of the study were summarized and presented in this chapter.

- The influence of weather parameters on number Cherelle of plant was not significant but it can be observed that the Cherelle production was more during monsoon season and because of that the number of pods harvested were more in summer season.
- The pods harvested during November (post monsoon season) was superior in pod weight. In contrast, the pods harvested during monsoon were inferior in pod weight. The seasonal variations were found significant.
- Pod weight had a significant positive correlation with morning relative humidity, afternoon relative humidity and rainfall, whereas maximum temperature, sunshine hours and evaporation showed a significant negative correlation.
- Number of beans per pod had a significant negative correlation with maximum temperature, solar radiation, soil temperature and evaporation during the initial stages of pod development but during the final stages of pod development these weather parameters had significant positive correlation. The influence of relative humidity, rainfall, rainy days and wind speed just opposite compared to temperature and evaporation.
- TSS had a significant positive correlation with maximum temperature, minimum temperature, sunshine hours, soil temperatures, and evaporation during the final stages of pod development whereas the minimum temperature, morning soil temperature and evaporation during the initial stages had a negative correlation.
- Multiple regression equations were predicted the pod weight and total soluble sugar content with good accuracy.

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- As per the projections based on RCP 4.5, there will be considerable reduction in cocoa production during 2030s and 2050s whereas the yield will recuperate during 2080s. The yield will be reduced by 24 per cent, 10 per cent for the periods 2030s, and 2050s respectively (Table 18) but in 2080s the yield will be improved by 10 percent.
- SUCROS-Cocoa model was validated and found that it can be used for predicting yield and physiology of cocoa.

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Crop Weather Modelling of Cocoa Production in Humid Tropics Under the Purview of Climate Change

by

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THESIS ABSTRACT

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Faculty of Agriculture

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2018

ABSTRACT

A field experiment entitled "Crop weather modelling of cocoa production in humid tropics under the purview of climate change (Theobroma cacao L.)" was conducted at Academy of climate change education and research, Vellanikkara from2017-18. The location is situated at 10°31' N and 76 °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 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 dry spell from November. The daily weather parameters viz., maximum and minimum temperatures, rainfall, morning and afternoon relative humidity, wind speed and Bright sunshine hours recorded at Agro-meteorological observatory, College of Horticulture, Vellanikkara were used for the study. The general climate of the location has studied for 35 years (1983-2017).

The highest monthly temperature recorded during the months of February, March and April. December and January are considered as the coldest months. Maximum morning Relative humidity was more than 90% during the months from June to October and the lowest morning Relative humidity was recorded in the months of December and January. The afternoon Relative humidity also followed the same trend. Highest monthly average wind speed was recorded in the months of December and January. The period from June to October is considered as the rainy season which contributed more than 85% of the total annual rainfall. The average annual evaporation is 1394.7 mm and the average monthly evaporation is 116 mm. The pods harvested during November (post monsoon season) was superior in pod weight. In contrast, the pods harvested during monsoon were inferior in pod weight. The seasonal variations were found significant. In the case of wet weight, it can be observed that seasonal impact of weather was insignificant. The wet weight of pods was superior in year 2014 followed by 2012 and then 2013. Similar trend was observed in the case of pod length, pod breadth and husk weight.

The yield and biometric parameters recorded at Cocoa Research Station, Vellanikkara was used for estimating various model parameters. Simulations in SUCROS-Cocoa was carried out for cacao trees of 1–11-year-old. Furthermore, the densities of model trees is bounded to 700–2500 ha-1. Climatic limitations of the model are an average day temperature between 10 and 40°C, and an annual precipitation of at least 1250 mm per year. The leaf area index (LAI) of shade trees should not exceed 3, and soil depth should be >1.5 m.

Simple linear correlations between important morphological, yield attributes and mean weekly weather parameters like maximum temperature, minimum temperature, mean temperature and temperature range, relative humidity (morning, afternoon, mean and difference between morning and afternoon relative humidity), wind speed, bright sunshine, were carried out. Pod weight had a significant positive correlation with morning relative humidity, afternoon relative humidity and rainfall, whereas maximum temperature, sunshine hours and evaporation showed a significant negative correlation. The minimum temperature showed positive correlation the beginning of pod formation and it was negatively influenced the pod weight during the final stages of pod development. Soil temperature at different depths were also negatively influenced the pod development. There was significant negative correlation with maximum temperature, solar radiation, soil temperature and evaporation during the initial stages of pod development but during the final stages of pod development these weather parameters had significant positive correlation. The influence of relative humidity, rainfall, rainy days and wind speed just opposite compared to temperature and evaporation. They had a positive correlation in the initial stages of pod development and negative correlation during the final stages. Increase in minimum temperature during the initial as well as final stages of pod development were detrimental number of beans per pod where as it has a positive influence during the middle stages