CLIMATE RESILIENT COCOA FARMING: STRATEGIES TO MITIGATE WEATHER RISKS

S. Elain Apshara*

Introduction

Cocoa (Theobroma cacao L.) produces beans which is the source for the world's favourite food, the chocolate. Cocoa is a crop of humid tropics which was introduced to India in the Western Ghats hills and plains region, where the agro climatic conditions found to be suitable. Wide cultivation started in 1970s and cocoa is being cultivated as a mixed crop under Arecanut (Areca catechu L., Coconut (Cocos nucifera L.) and to some extent in Oil Palm (Elaeis guineensis) gardens in states of Kerala, Karnataka, Tamil Nadu and Andhra Pradesh. Most of the international cocoa research institutes concluded that both the vegetative and reproductive growth phases of cocoa are influenced by the complexity of environmental factors and cocoa is vulnerable to climate change effects. Cocoa being shade tolerant is generally grown as under- storey crop either in agro-forestry systems of Central/ South American and West African nations or in palm based cropping systems in Asia-Pacific regions. CPCRI started its cocoa research way back in 1969 with germplasm introduction and breeding followed by cropping systems research, production strategies, physiological influences, protection measures and post harvest technologies. The physiological characteristics of cocoa have been fairly well understood through extensive studies (Balasimha, 2011). Perenniality of the crop offers wide variation and the results of cocoa studies were integrated into various physiological production models as well, to exploit its potential in a sustainable manner (Daymond and Hadley 2005; Balasimha, 2012).

Impact of Agro Climatic Conditions

Most of the world's cocoa is grown in a narrow belt, 10 degrees either side of the Equator in humid tropics with regular rains and a short dry season. The basic temperatures between 21-23^0 C, with a fairly constant rainfall of 1,000-2,500 mm per year are preferred without hot dry winds and drought. In cocoa producing countries of Asia, the mean minimum and maximum temperatures are in the range of 18-24^{0}C and 26-32^{0}C. These temperatures are influenced by altitude, latitude and distance from the sea. Temperatures decrease steadily with altitude and main cocoa growing regions are found in a range of 650-1000 m.

When cocoa was introduced to India, the agro climatic condition was given the major concern similar to the other beverage crops, tea and coffee, which occupied the top and middle hills where cocoa was planted in the lower hills. Wood (1964) documented that the then states of Kerala, Madras and Mysore in South India which got sufficient rains from both monsoons and with short dry seasons were selected for cocoa cultivation. Initial introductions were made in rubber and coffee growing zones of Kerala and Mysore and in Madras state, Nagercoil in Kanyakumari Dt., Courtallam and Tenkasi in Tirunelveli Dt., Palni Hills and Anaimalai Hills. In Cardamom hills and Shevroys, cocoa was planted at high altitudes at 800 m and 1300 m respectively. In the North Eastern states, few introductions were made with cocoa imported from Malaysia in 1963. In Assam, at 150 m, Cachar and Lushai Hills were found to be suitable with alluvial soils in valley bottoms and in Orissa, 350 m was suggested. In CPCRI Research Centre Kahikuchi Assam, when temperature goes below 100^C during winter season, wilting of leaves noticed in 30 year old cocoa trees, but further they rejuvenated withstanding the cold injury and so cocoa can be suitably grown in NE states. In Andaman Islands also few plantings were done. These indications confirmed the importance of selection of site for cocoa cultivation. Of late the climatic conditions prevailed in arecanut and coconut gardens were found as compatible for cocoa and wide area expansion was taken up in southern states. The climatic conditions showed some variations in these regions also. Long dry spells are observed in Northern Kerala and coastal Karnataka of about 5-6 months compared to southern parts under rainfed coconut gardens but the situation is better in irrigated arecanut gardens (Vijayakumar et al., 1991). Two dissimilar crop patterns were observed in cocoa under rainfed and irrigated conditions (Balasimha, 1987). Intensity and distribution of rainfall decide the pattern of cropping in mature cocoa. If rainfall is less than 1,250 mm, the crop needs to be irrigated during the rainless period.

Cocoa growing areas have uniformly high humidity, often 100% during night falling to 70-80% by day. This may go still lower during dry seasons. The plants grown at lower relative humidity produce small leaves and tend to be curled and withered at the tip. Persistence of high humidity increases the incidence of fungal disease. Changes in relative humidity have a greater effect on stomatal resistance than levels of temperature. As relative humidity falls, stomata close and resistance increases to restrict

* Principal Scientist (Hort.-Fruit Science),Horticulture Section/ Cocoa Gene Bank, ICAR- Central Plantation Crops Research Institute- CPCRI,Regional Station, Vittal, Karnataka

transpiration. Period of drought with low RH can cause wilting of leaves, if water is given before they fall, they will recover quickly.

Cocoa is grown on a variety of soils throughout the world. Most of the present cocoa plantations of India are in laterite soils and are found to be adequately suitable for cocoa growth. Black soils and alluvial soils are also suitable for cocoa if not too wet or too shallow. The ideal soil for cocoa should have depth of 1.5 m, organic matter-3.5%, C/N ratio->9, base exchange capacity->12 me/ 100g soil, base saturation->35% (Wood and Lass 1985). Cocoa is a deep rooted crop and vertical penetration of cocoa roots is up to 3.5 m. Under monocropping system, root growth of cocoa is concentrated within 25 cm radius and under mixed cropping system, 42% of total and 24% of fine roots are confined to 25 cm radius from the tree. Due to tap root system and high CEC of cocoa roots, cocoa tend to be highly competitive to main crop. Thus, it is essential to meet the water and nutrient demand of both component crops in mixed crop situations adequately (Ravi Bhat, 2002).

Multi Location Trials (MLT)

To assess the adaptability and stability of cocoa germplasm collections, elite clones and hybrids developed through breeding programmes, systematic multi location trials (MLT) in different agro climatic condition is very important. ICAR- CPCRI is conducting cocoa trials in its own centres, 2 in Kerala (Kasaragod and Kayamkulam), 2 in Karnataka (Vittal and Kidu), 1 in West Bengal (Mohitnagar) and 1 in Assam (Kahikuchi). Through AICRPP (All India Co-ordinated Research Project on Plantation Crops), cocoa trials are running in 7 centres in TN, AP, Maharashtra and Assam. These are mainly to identify varieties performing best in all locations as well as select region specific varieties. Without multi location testing, supplying planting materials from traditional belts to non-traditional regions in huge quantity will affect the performance and waste of resources. Area expansion should be taken up in a phased manner especially in NE states. Apart from improvement of production and productivity, industrial value and quality of beans should also be considered from other regions. Crop cycle differs based on the agro climatic situation and the management practices specifically pruning and training of plants should be modified accordingly.

Cocoa Trials in AICRP Centres

- Veppankulam and Aliyarnagar, TN : under coconut
- Amabajipeta and Vijayarai, AP : under coconut and oil palm
- Navsari, Gujarat : under coconut
- Ratnagiri, Maharashtra : under coconut
- Kahikuchi, Assam : under coconut

Apart from these trials, 94 front line demonstration plots were established under participatory research cum demonstration plots scheme funded by Directorate of Cashewnut and Cocoa Development (DCCD), Kochi in 8 taluks in Karnataka and 1 taluk of northern Kerala. Performance of selected clones assessed in 12 gardens planted during 2004, showed 1 kg dry beans in Bantwal, Sampaje and Kasaragod taluks (Kalavathi and Elain Apshara 2011).

These studies showed that the agro climatic conditions prevailed in the locations contributed to the performance of cocoa genotypes. New set of FLD plots on cocoa were established at AICRP centres also with 15 clones including drought tolerant ones to assess the influence of changing climates on the performance of cocoa. Crop cycle differs with the prevailing agro climatic situations.

Cocoa Trials in CPCRI Centres with different Agro Climatic Conditions

State	Karnataka		Kerala		West Bengal	Assam
Centre	Vittal	Kidu	Kasaragod	Kayamkulam	Mohitnagar	Kahikuchi
Region	West Coast Hills & Plains	West Coast Hills & Plains	West Coast Hills & Plains	West Coast Hills & Plains	Terrai Region	Eastern Himalayan Region
GPS Lattitude Longitude	 12.78° 75.11°	 12.70° 75.57°	 12.52° 74.97°	 9.15° 76.51°	 26.52° 88.66°	 26.10° 91.61°
MSL	73-92 m	291 m	10.7 m	3.05 m	91 m	50 m
Rainfall	3670 mm	3950 mm	3500 mm	2564 mm	3000 mm	1500 mm
Temperature	28-36°C	25-33°C	23-31°C	32°C	8-35°C	10-35°C
RH	75-80%	80-85%	80%	70%	70-80%	85-90%
Soil	Laterite admix with sand & alluvium	Red and sandy laterite	Sandy loam	Sandy loam	Loam	Clay loam
pH	5.25	6.6	5.9	5.0-6.0	5.5	4.5-5.5

Cocoa Crop Cycle in Different Regions

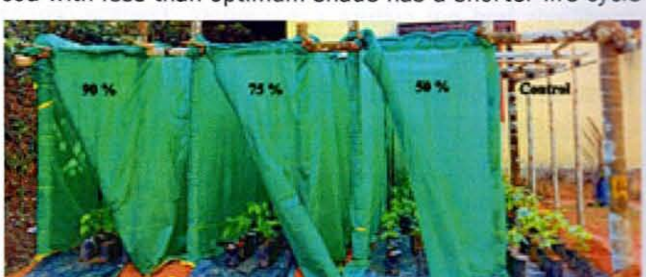
Crop cycle	Vittal (Karnataka)	Kasaragod (Kerala)	Ambajipeta (AP)	Veppankulam (Tamil Nadu)
Main crop season	May-Aug.	May-Aug.	March-June	Mar.-June
Pruning	Sep.	Sep.	July-Aug.	July
Flushing	Oct.	Oct.	Sept.	Aug.-Sept.
Flowering	Nov.-Dec.	Nov.-Dec.	Oct.-Dec.	Oct.-Nov.
Fruit set	Jan.-Apr.	Jan.-Apr.	Nov.-Feb.	Dec.-Feb.
Off season bearing, if any	Oct.-Dec.	Jan.-Feb.	July-Sept.	-

Impact of Shade

Traditionally cocoa is a forest crop grown under tall trees and commercially also it is under shade because it needs crop cover for its better development and yield. But the intensity of shade requirement varies from place to place and growth stages. At seedling stage, cocoa need shade of more than 50% and the requirement reduces as they mature. Nursery should be established in the shaded area. Green shade nets (50-75%) are being used in commercial nurseries throughout the dry period (Elain Apshara, 2010). When seedlings are grown under heavy shades, a period of ten days of hardening by exposing to sun light is practiced before transplanting. In the field, during the post monsoon and summer seasons, covering seedling with plaited coconut fronds is being followed upto two years (Elain Apshara and Venkatesh Hubballi 2012). The shade provided to young plants has a major role to play as it decides the survival, early growth, canopy formation and establishment of the crop, which is essential as life irrigation. Shade has pronounced influence on CO2 assimilation and nutrition also. Light saturation occurs even at 20% of light in Ghana and it showed that light intensity is vital for nutrient response. Under Indian conditions, 10-15 years shade is required, in the later years since cocoa leaves have a self shading effect which helped in survival of the trees with assured irrigation. Selection of suitable shade trees and spacings are very important. If shade is not sufficient, there will be high weed growth, insect infestation and high percentage of small and inferior beans. It was observed at Vittal that tea mosquito bug incidence was so severe in unshaded gardens causing economic loss. If shade is too much it will affect the yield of cocoa. Cocoa with less than optimum shade has a shorter life cycle (Nair et al., 1996). Heavy shade induces long internodes and few branches, while too much light may induce short internodes and more branching, resulted in bushy trees.

Various combinations of permanent and temporary shade plants were tried in all cocoa producing countries. In case of temporary shades, once the cocoa canopy develops, they are removed to increase the light transmission. Plantain, Tapioca and Gliricidia trees are used as temporary shade trees for cocoa. Some of the leguminous shade species like Erythrina sp, Leucaena leucocephala, Gliricidia sepium, Cordia alliodora has been grown as shade trees for cocoa in Brazil, African and Latin American countries including related speces and genera like Theobroma spp. and Cola nitida. Erythrina lithosperma is widely used in Sri Lanka and Indonesia as conventional shade. In some cases, one shade tree e.g. Gliricidia is planted for the young cocoa and replaced by another e.g. Albizzia for the mature tree. In Malaysia, cocoa under- planted with oil palm showed increased productivity. Coconut, arecanut and rubber are used as shade trees in Malaysia, India and Brazil. In general, in all cocoa producing countries multipurpose trees as shade trees are preferred.

In India, cocoa is being planted at 2.7 m x 5.4 m spacing in arecanut garden spaced at 2.7 m x 2.7 m, cocoa is being planted in the centre of four arecanut palms by leaving an areca row in between which is mostly utilized for growing Banana. To increase the income per unit area several crop combinations were tried and the High Density Multispecies Cropping System model, Arecanut + Cocoa + Banana + Pepper (trailed on arecanut) is considered as a profitable system (Elain Apshara and Jaganathan 2011) and location specific models are developed to utilize the available resources to the maximum possible. A system of



Seedlings under different shade levels

Trees under different shade levels

same time planting of arecanut and cocoa at 3 m x 3 m also offers optimal shade, good growth and yield. In coconut plantation of 7.5 m x 7.5 m spacing, cocoa is planted at 2.7 and 3 m distance in the centre of two rows of coconut as single hedge. When the spacing of coconut is more two rows of cocoa can be accommodated between two rows of coconut as a double hedge system and the spacing of cocoa may be 2.5 to 2.7 m. However, it is advised to leave 3 m from the base of coconut palm in order to avoid competition for water and nutrients between the plants. Planting single hedge of cocoa in the middle of palms and one plant in the coconut row, planting cocoa in triangular system between two rows of coconut is also followed in Kerala. Coconut based multi species cropping system involved Coconut + Cocoa + Banana + Pepper (trailed on coconut), Coconut + Cocoa + Nutmeg/ Clove + Pine Apple etc. (George Thomas et al. 2010). In oil palm gardens of 9.9 or 10.5 m triangular plantings, cocoa is grown at 2.4 m spacing. Cocoa should be 2 m away from the base of palm. Shade in oil palm plantations is very high and so age of the palms and wider spacing are to be considered (Sujatha and Bhat 2012). Comparative studies on cocoa clones under arecanut and coconut shades and different spacings are being taken up in the evaluation trials of CPCRI. Twenty five mixed lines of cocoa planted as clones under arecanut and coconut canopies showed significant differences in their growth and yield performance. VTLC-56, VTLC-57, VTLC-1, VTLC-6, VTLC-59 and VTLC-67 recorded an average of 55.27, 55.43, 51.26, 50.42, 44.23 and 44.13 pods/tree/year respectively under arecanut. Under coconut, the clones, VTLC-66, VTLC-1, VTLC-57, VTLC-59, VTLC-65 and VTLC-6 were found to be good with yield efficiency of 61.03, 57.64, 56.13, 54.33, 54.30 and 52.43 pods respectively. Among all the clones, VTLC-1, VTLC-57 and VTLC-6 performed well under both the canopies (Elain Apshara et al., 2002 and Elain Apshara, 2012). Between oil palm and coconut, the cocoa clones performed well under coconut in AP since shade levels are little higher in oil palm gardens. Shade tolerance studies were initiated with 8 varieties planted under 50%, 75% and 90% shades.

Persistent winds damage cocoa canopy and cause defoliation. Cooling by wind induces wider opening of stomata and shoots will be dehydrated by wind. The effect of wind damage will be severe in unshaded cocoa garden. Mangifera indica, Calophyllium antillanum, Dracaena spp, Hibiscus spp., Eugenia aromatica, E. malaccensis, Swietenia macrophylla, Tectona grandis, Cinnamomum zeylanicum, Cashuarina are the mixture of trees grown as wind breaks to protect cocoa in many countries. Cocoa is compatible many agro forestry and fruit trees and so these models can be followed in NE regions. Mixed cropping will give the benefits of afforestation than monocropping, which nullifies the deforestation complaints often occurs with plantation sector.

Impact of Irrigation

Cocoa is usually grown in areas where water availability is adequate but Trinidad, Ghana, Ecuador and India are affected by periodic droughts. Decrease in soil moisture results in reduced photosynthesis and yields and so supplemented irrigation methods like flood, sprinkler and drip irrigation have been used. Water supplies improve growth and development of cocoa. Drip irrigation is found to be superior in water limited conditions for judicial usage of available water and yield was significantly increased. Cocoa is now grown widely under coconut and arecanut as an irrigated crop especially in non-traditional areas of Tamil Nadu and Andhra Pradesh states. As rainfall occurs only from June to October in traditional areas of Kerala and Karnataka, the remaining period remains dry for which drip irrigation is being followed. Sprinkler irrigation to some extent causing mechanical damage to the flower cushions on the trunk and the salts in water affects the foliages of cocoa. Through drip irrigation 20 liters of water/day/tree at recommended level of fertilizer (100:40:140 g N: P_2O_5: K_2O /tree/year) is optimal to get maximum yield from cocoa, when it is intercropped with arecanut. It was observed that stomatal resistance was higher (10l/day) which reduced photosynthesis and transpiration, but there was no mesophyll limitation due to water stress. Drip irrigation requirement of cocoa is computed by considering the following thumb rule. Based on modified penman method, it is derived that one mm of pan evaporation is equivalent to 3.3 litre of water. This will enable farmers to know the water requirement based on weather data of particular location. This implies that 20 lit of water/ day/ tree are required through drip if evaporation is 6mm. Thus, water requirement is less during winter (November - December) and increases during summer (March - May) (Sujatha and Bhat 2012). Through Fertigation, with Urea - 107g, Di Ammonium Phosphate (DAP) - 145g, Muriate of Potash (MOP)- 180g is recommended.

Breeding for Drought Tolerance in Cocoa

Breeding efforts for drought tolerance needed combined studies on field measurements, controlled conditions and pot culture experiments. Climate change became an immediate concern to both producing and consuming countries because cocoa is a high value crop contributing enormously to the worlds economy. Eskes et al. 2000 designed the working procedure for field screening and physiological evaluation of cocoa germplasm which was accepted and followed by cocoa researchers. It was concluded that cocoa yield can be considered within a relatively simple physiological framework that helps to explain yield capacity and growth of cocoa genotypes. For example, measurements of flower production, pollination rates and cherelle (young fruit) wilt will provide valuable information on the dynamics of pod production and could explain yield limitations occuring under certain climatic conditions. Measurements of changes in trunk circumference or girth of stem and length of the main branches can provide non-destructive estimates of rates of biomass production. If combined with yield measurements, estimates can be made on the partitioning of carbon between structural and yield components of the tree and ultimately to evaluate the cropping efficiency of cocoa. Measurements of canopy size and light interception can provide useful information on the effectiveness of cocoa tree in converting light energy into yield. Sophisticated equipment, such as canopy analyzers, can provide more comprehensive information about canopy architecture.

Visual Estimates of Vigour and Physiological Traits in Cocoa

(i) Vigour of cocoa trees

Vigor of cocoa is strongly affected by the environment, soil fertility, rainfall (amount and distribution) and temperature. Efron 2000 opined that knowledge of the potential vigour of trees is important from the horticultural point of view, mainly for recommendations related to planting density/ spacing and pruning levels/ shade regulation and further the correlations with physiological interventions. Visual observation on a 1 to 5 rating scale can be very useful in breeding to classify individual trees, families and clones into plant size categories (small, intermediate and large). The measurements are annually taken at 30 cm from ground level for seedlings and at 15 cm for clones. Efron et al. 2003 suggested that the relationship between yield, vigour and yield efficiency are important in clonal evaluation trials planted at one density. Among 21 hybrids as clones evaluated at CPCRI under high density planting, the hybrids VTLCP-6, VTLCP-5 and VTLCP-1 were identified with high harvest efficiencies 0.88, 0.66 and 0.56 which had more vigour 32.3, 38.3 and 35.4 cm with high pod yield of 68.7, 61.7 and 50.9 pods/ tree/ year respectively (Elain Apshara et al., 2008). In other germplasm trials also yield is being correlated with vigour and canopy area. With all the above views and approaches Hadley 2000 detailed the visual estimates of physiological traits in cocoa (Table 1) which are to be taken in clonal plants on plot basis with 6- 8 trees and in hybrid plants on individual tree basis.

(ii) Branching, canopy size and shape

Branching pattern in cocoa is very systematic and specific with orthotropic (chupon) and plagiotropic (fan) branches in multiple tiers. The intensity of branching, shape of the canopy are to be evaluated annually by a 5 point scale. In the intercropping system in India it is important to maintain minimal number of branches upto first and second tier to manage the crop easily. The total plant height, the first branching height or the jorquetting height and the canopy spread both east west and north south directions are being measured annually. Considering the canopy as cone shaped the canopy area is calculated using the formula πrl, whereas r= EW+NS/ 4 and l= $\sqrt{r2}$ + h2, h= canopy height. Canopy size of 15-20 m2 is found to be optimal in the arecanut garden and 20-25 m2. In clonal trials, these observations are made on a plot basis and carreid out once a year during the first five or six years after planting. Depends on cropping systems high to medium vigour with optimal canopy is preferred by many countries, whereas genotypes with small canopy is prefered for high density planting .

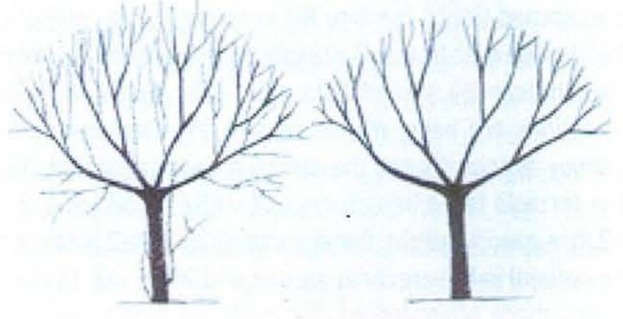
(iii) Pruning intensity and canopy architecture

In many cocoa producing countries good local horticultural practices include systematic pruning and training measures except in West Africa. It is an important opera- tion in cocoa especially, when it is grown as an intercrop, to

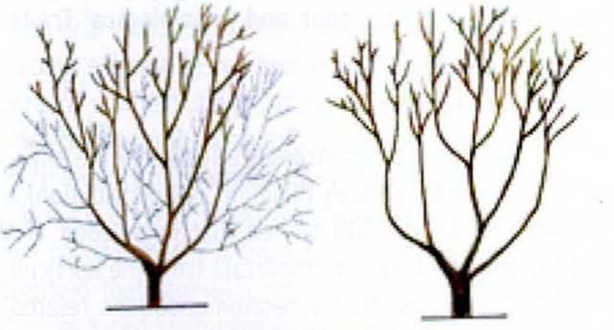
Physiological 1	Flowering, fruiting, cherelle wilting and leaf flushing intensity evaluated on a 1 to 5 point scale (1= absence, 5 is abundance)			
Genotype	Flowering	Fruiting	Wilting	Flushing
Physiological 2	Branching intensity (bi) and canopy shape (cs) estimated on a 1 to 5 point scale (1= low branching intensity or droopy canopy shape and 5= high branching intensity and erect shape)			
Genotype	bi	cs	Bi	cs
Physiological 3	Canopy density (cd) and light transmission (lt), estimated bi- annually on a 1 to 5 point scale. For canopy density 5= dense canopy and 1= very open canopy, for light transmission 5= more than 40% light transmission (sun- flecks), 4= 20-40%, 3= 10-20%, 2= 5-10%, 1= 1-5% and 0= 0% transmission of light (no sun- flecks)			
Genotype	cd	lt	cd	lt
Physiological 4	Canopy pruning intensity, measured on a 1 to 5 point scale (1= few leaves/ branches pruned and 5= many leaves/ branches pruned)			
Eskes *et al.*, 2000				

avoid inter plot competition for canopy space. The main objective of pruning is to maintain the shape of the cocoa plant to make it more productive and efficient. Pruning system varies with young plants, mature trees, seedlings as well as clones. Before conducting any modifications to the canopy the branching pattern of cocoa should be well understood. Pruning will decide the number of jorquettes per tree, fan branches per jorquette and height of first jorquette.

Formation pruning is practiced in young plants which start to develop the first jorquette when they are 14 months old. It is desirable to restrict the jorquetting height to 1-1.5 m under the intercropping situations. To shape the canopy to desired size and to maintain the canopy architecture structural pruning is done in mature trees. For pruning of seedling material, first the height of first jorquette is adjusted between 1 to 2 meters and 3- 4 fan branches are retained with vertical height restricted to first jorquette and an umbrella shaped canopy is maintained (Fig. 2). A spread of 3.8 to 4.0 m and a height of 2.7 m are considered as ideal canopy architecture for optimum yield in seedlings. For pruning of clonal material (either grafted or budded plant), in the first year of planting, primary pruning is practiced to form a supporting framework with one or more upward growing main stems. Then drooping or inward growing branches are removed. Secondary pruning is suggested to develop umbrella shaped canopy with about 3.8 m to 4.2 m spread and 2.7 m height depending upon the space and main crop in which cocoa is under planted/ grown. In order to understand and elucidate optimum canopy shape and structure of cocoa, different spacing and canopy sizes were studied (Balasimha, 2001, 2007) which showed significant differences in crop yield. Pruning should be done to the extent of retaining 20-30 leaves/ developing pod. The proper pruning of cocoa ensures adequate ventilation in garden, maintain



Pruning in seedling plant



Pruning in grafted plant

tree height, makes spraying and harvesting operations easier. When cultivated as mixed crop under palms a maximum of two storey canopy architecture may be maintained. Chupons must be removed very often and care should be taken to give minimal disturbance to the plant with flowers, cherelles and pods. Exposed wood surface or cut portion should be always swabbed with fungicidal paste (Bordeaux paste) immediately after the pruning.

stematic and regular prunings were taken up annually in genotypes to utilize the efficiency of selected cocoa lines. 20 progenies of different cross combinations and 10 clones were assessed for their performance under arecanut in denser plantings (2.7 m x 2.7 m) with severe prunings, which showed considerable difference in their growth and yielding behaviour in their initial years of growth. The progenies VTLCP- 5, 6, 15 and 20 had comparatively compact canopies and had high dry beans yields of >1.5 kg/ tree/ year at the age of 7 years. Among the 10 selected clones, VTLCC-7 and VTLCC-8 recorded more yield with medium canopy. Comparative trial on seedlings and clones of 12 selected genotypes exhibited considerable difference in their first branching or the jorquetting heights, earliness in flowering, distribution of pods in canopy etc. At age of 6 years grafted plants of all the clones showed precocious and high yielding behaviour and among seedlings, bearing was not uniform. Among the clones the yield ranged from 21.6 to 44.2 and among the seedlings it ranged from 15.1 to 30.5 pods/tree/year. 11 genotypes as grafts yielded more than seedlings at Vittal under Arecanut and 6 at Kasaragod under Coconut. Bean characters were same with genotypes. Comparative trial on clonal plants of 13 parents and 12 progenies showed that clones of progenies exhibited greater vigour, optimal canopies and high pod yields. This showed that different planting materials required different pruning methods and with systematic pruning the potential of genotypes can be explored.

(iv) Canopy density and light interception

The canopy density (leaf density inside the canopy) and light interception are related to the leaf area index which may vary between genotypes. In cocoa self shading of leaves are more. Light interception by the canopy is visually determined in the middle of a sunny day by estimating the light transmission. Dense canopy may intercept more or less light, depending on the position of the leaves which is more or less vertical. Incident radiation is measured above the canopy, but below the overhead shade, and transmitted radiation is measured below the cocoa canopy, avoiding sun- flecks. Light interception is calculated as (incident minus transmitted radiation/ incident radiation).

Light interception over cocoa canopy under different shade levels

50% shade net

75% shade net

90% shade net

(v) Flowering, fruiting and flushing rates

Intensity of flowering, fruiting (presence of new cherelles), cherelle wilting and leaf flushing can be observed by applying a subjective 5 point observation scale. In Karnataka, the main flowering season starts in November- December, fruit development in summer (Temperao crop), harvesting correlates with monsoon during May-August followed by annual pruning in September which induces further flushing and flowering. In vegetatively propagated plants in the initial years, continuous flowerings are noticed. Water stress affects all these phases of cocoa, flushing is inhibited by water stress. From pollination to pod ripening, the duration is 5-6 months, taking a sigmoid curve. A natural fruit thinning mechanism occurs in cocoa and called as 'cherelle wilt'. Increased rate of cherelle shedding commences up to 50 DAP (days after pollination) followed by a second peak at 70 DAP and beyond 95-100 DAP wilting does not occur. Water deficit, especially when more pronounced, this physiological wilt will cause more loss. In all cocoa areas, regardless of shade cover, a marked decline in flowering near the end of the rainy season was observed when rainfall was very high. Rains after a long dry period resulted in profuse flowering called 'crazy' flowering in cocoa.

Drought Tolerance Studies at CPCRI

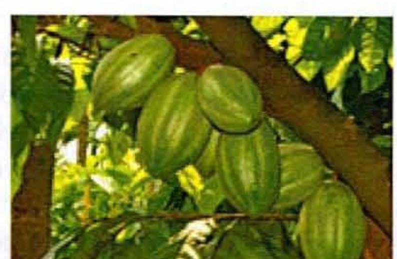
Cocoa in its current growing system has to undergo a period of water scarcity for five to six months and so it is important to identify genotypes tolerant to these adverse situations. Central Plantation Crops Research Institute (CPCRI) started its breeding strategies with germplasm collection and conservation program in 1969 and continued until now with significant success. A total of 531 collections comprising of accessions from Amazon, Brazil, Ecuador, England, Ghana, Jamaica, Malaysia, Mexico, Nigeria, Trinidad and local collections from farmer's fields of Wayanad in Kerala, Shiradi ghats of Karnataka and Kanyakumari of Tamil Nadu are being conserved in field gene banks of CPCRI, Regional Station, Vittal, Karnataka. Apart from cocoa germplasm collections, 40 hybrids, elite clones, fine cocoa types are being maintained in various trials under arecanut and coconut. They are continuously being evaluated for their adaptability in the introduced environment with their growth and yield performance, stability over different cropping systems, locations, potential productivity and resistance to both biotic and abiotic stress.

Cocoa plants are susceptible to environmental conditions, especially temperature, and drought, and considerably influence pod yield (Daymond et al. 2000). Cocoa is very sensitive to water scarcity and undergoes a period of low moisture stress for five to six months in its current growing condition in India. Breeding for drought tolerance is unique to our country and is taken up with systematic screening of available germplasm as well as hybridization programs. Screening of accessions is conducted for physiological parameters like stomatal resistance, chlorophyll fluorescence, proline accumulation under stress, and studies on seed germination under low osmotic potential, etc. A total of 216 cocoa genotypes have so far been screened for physiological and biochemical parameters under different trials (Balasimha 1999). In all these studies, field measurements were taken during unstressed (October) and stressed (March) conditions. Few Nigerian collections have been identified as drought-tolerant and used for hybridization with high-yielding Malaysian collections under two progeny trials. Two hybrids, VTLCH 3 and VTLCH 4 and a clone VTLCC 1, have been released as varieties suitable for cultivation under water-limited conditions in the country.

Drought tolerant cocoa varieties of CPCRI

VTLCH 3

VTLCH 4



VTLCC 1

Drought symptoms in cocoa seedlings at 20% FC

Soil moisture content (%)	20% FC
Physiological traits	
Stomatal resistance (s/cm)	≥ 10.77
Conductance (mole/m²/s)	≤ 0.36
Transpiration rate (mmol/m²/s)	≤ 0.99
Leaf water potential (Bar)	≥ -19
Photo (μmol/m²/s)	≥ 9.62
CO_2 int (ppm)	≥ 300
WUE (Pn/E)	≥ 10.49
Pn/Cint	≥ 0.032
Chlorophyll fluorescence (Fv/Fm)	≥ 0.31
Epicuticular wax (μg/cm²)	≥ 20.58
Biochemical metabolites	
Total Soluble Sugar (μg/gMF)	≥ 16.86
Amino Acid (μg/gMF)	≥ 2.05
Proline (μg/gMF)	≥ 0.048
Protein (μgBSA/mgMF)	≥ 0.84
Antioxidant enzymes	
MDA (mmol)	≥ 0.04
SOD (Specific activity/ min/protein)	≥ 0.5
CAT (Specific activity/ min/protein)	≥ 0.07
POX (Specific activity/ min/protein)	≥ 0.83
PPO (Specific activity/ min/protein)	≥ 0.147

Impact of Water Logging

Waterlogging is an important climatic factor affecting cocoa plants. Flooding is of common occurrence in some cocoa growing regions of Brazil, Ghana, Ivory Coast and Nigeria. This is due to excessive rainfall resulting in hypoxic conditions in soil. Due to this growth and leaf area developments will be decreased. Flooding also causes reduction in photosynthetic rates and stomatal conductance. Genotypic variations in relation to waterlogging have been reported and some genotypes are found to be tolerant. Growth inhibitions and decreased photosynthesis reduce pod production considerably. Continuous waterlogging leads to changes in plant morphology including adventitious roots and lenticels formation. Field planting of cocoa clones in post- monsoon season is recommended in high rainfall zones. Improving drainage facilities, by deepening the channels surrounding the plot and in between two rows of cocoa is being practiced. Both upper and lower

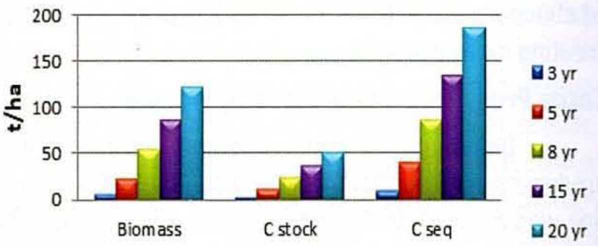
Amazon clones found to be tolerant to waterlogging both at Thrissur (lower Peechi Dam) and at Vittal (plot adjacent to river inside CPCRI campus).

Carbon Sequestration

Mitigation of green house gas emission is one of the important aspects related to quest against climate change. Carbon sequestration by terrestrial biomass is one of the mitigation options used for reduction of green house gases (GHGs). Agroforestry systems provide opportunity for carbon sequestration under clean development mechanism. Arecanut cocoa based cropping systems produce abundant biomass to qualify for this. The standing biomass increased over time indicating accumulation of biomass in stem and also due to increase in yield by arecanut and cocoa plant with age up to 20th year of planting. Cocoa produces stable yield after five years of planting and arecanut from eight years after planting. Around 30-50% of photosynthetically active radiation is transmitted through arecanut canopy and cocoa, with its compact and high leaf area, is able to intercept 90% of the remaining PAR. Cocoa production under shade trees has been reported to be 1 t/ha/year in Costa Rica however, biomass production under arecanut and cocoa agro forestry system under tropical conditions prevailing in India is higher.

Climate Change

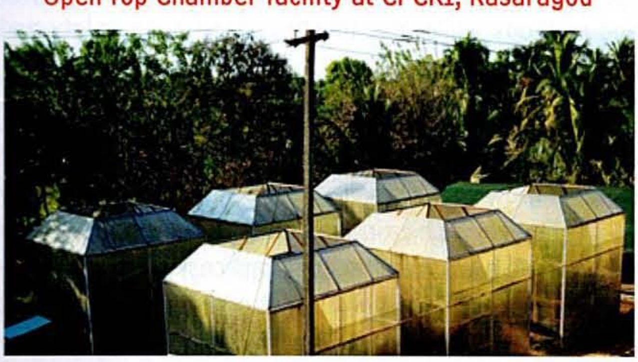
In order to fill the gap in knowledge on response under long term exposure at whole plant level to elevated CO2 and temperature, cocoa plants were grown in Open Top Chamber facility at CPCRI, Kasaragod, wherein two elevated CO2 levels (550 and 700 μmol CO_2.mol^{-1}) and elevated temperature (+2⊠C above ambient OTC) were maintained apart from the chamber control (ambient temperature and CO2). These seedlings are exposed to above mentioned conditions for 2 years. Results indicated that the elevated CO2 significantly increased net photosynthetic rates (PN) while the transpiration rates (E) remained almost similar to that in ambient CO_2 conditions. As a consequence, the instantaneous water use efficiency (PN/E-WUE) has increased by 51% at 550 μmol CO_2.mol-1 and by 112% at 700 μmol CO_2.mol-1 as compared to that in chamber control. Elevated CO_2 and temperature increased the concentrations of chlorophyll a relatively more than that of chlorophyll b and thus increased the chl a/b ratio. Elevated CO2 and temperature also increased the concentration of total soluble sugars and starch in leaf tissue. The chlorophyll transients such as F0, Fv, and Fm did not significantly differ due to growing condition. The Fv/Fm was more than 0.8, indicating that plants were not under stress in all the treatments. Results indicate that elevated CO_2 and temperature may prove to be beneficial for cocoa plantations in climate change scenarios, particularly in view of the fact that cocoa is grown as an intercrop in the coconut gardens and mostly are maintained under water-non limiting conditions. In addition to increased physiological water use efficiency in elevated CO_2 and temperature conditions, there is a need to increase the field level (agronomic) water use efficiency through drip irrigation or fertigation for harnessing the potential benefits due to elevated CO_2 and also to avoid or minimize the adverse effects, if any, of elevated temperature in future climates in cocoa growing regions of India.



Total (Areca+Cocoa)

Carbon sequestration in areca and cocoa system

Open Top Chamber facility at CPCRI, Kasaragod



Carbon sequestration in areca and cocoa system

CONCLUSION

Cocoa exhibits considerable genetic variation in a range of physiological and morphological characteristics and the interaction between particular genotypes and their environments should be extensively studied. Multiple clones should be tested in multi locations covering different agro climatic conditions and different crop canopies. Improvement in traditional cropping systems as well as the expansion in non-traditional areas should be looked into with respect to climatic changes. Care and continuous surveillance should be taken on established and emerging pests and diseases of cocoa in relation to weather variables. Collaborative breeding programs with Asia-Pacific nations will enable us to tackle the region specific and common problems. As discussed in this chapter, physiological parameters in the growing environment should be validated with controlled experiments to identify suitable abiotic stress tolerant varieties as well as management strategies.