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Chapter 4

Arecanut and Cocoa

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1. Introduction

Agriculture is affected by climate change and weather variability. Climate change has long term negative impact on agricultural productivity all over the world (Nellemann *et al.*, 2009). A small climatic instability can cause some devastatingsocio-economic consequences in many developing countries due to the dominant role of agriculture and its primary dependence on rainfall. Thus, accurate aassessment of yield response to future climate is needed to prioritize adaptation strategies. Proliferation of pests and diseases, reduced recovery and low resource use efficiency are the imminent consequences of climate change scenario. Nelson *et al.* (2009) reported that an increase in temperature is mainly due to global warming, which reduces crop yields and encourages pest proliferation. Changes in temperature affect the crop yield mainly through phenological development process. Phenology is a good indicator of global warming (Chmielewski and Rötzer 2000).Therefore, it necessitates a cases tudy to identify the relation between climate and crop growth and yield, focusing on a regionor climatic geography. Weather variability influences the yield and sustainability of perennial plantations considerably as economic yielding life spreads over several decades. In perennial crops, the productivity is influenced not only by rainfall and temperature but also by other weather parameters like relative humidity, evaporation and sunshine hours. In regions where perennial crops are economically and culturally important, improved assessments of yield responses to future climate are needed to prioritize adaptation strategies.

Arecanut (*Areca catechu* L.) and cocoa (*Theobroma cacao* L.) are the two major cash crops in humid tropics of India. These perennial plantations are sensitive to various biotic and abiotic stresses. Arecanut, which belongs to family *palmae*, grows to height of 10-15 m with a crown of 8-9 leaves. In arecanut, flowering initiates in 4th year and yield stabilizes by 8th year. Cocoa belongs to family *Malvaceae* (formerly *Sterculiaceae*) and grows to a height of 2.0-2.5 m with 15-20 m^2canopy area. In cocoa, flowering initiates in 3rd year and is segmental in repeated phases. The flowering to harvesting period is one year in arecanut and 150-180 days in cocoa. The average yield levels are 1.5-3.0 kg $palm^{-1}$ in arecanut and 1.0 - 2.0 kg $tree^{-1}$ in cocoa in West coast region of India. The arecanut-cocoa system is efficient and economically feasible. In the tropical belt where arecanut and cocoa are grown (28° N and S of equator), precipitation is confined to six months from June to November with average rainfall of 3700mm. Insufficient water has been a major limiting factor in post monsoon season (December-May) due to high evaporative demand of arecanut. In India, it is cultivated in 0.45 m hectares with a production of 0.73 m tonnes and productivity of 1400 kg ha^{-1} (GOI, 2015). The tropical plant, cocoa (*Theobroma cacao* L.), which is the source of chocolate is endemic to Amazon basin. Its cultivation has subsequently extended to tropical and subtropical regions of South and Central America, West Africa and Asia-Pacific. Cocoa is cultivated as a component crop in arecanut, coconut and oil palm in 78, 000 ha with a production of 16, 050 tonnes and productivity of 475 kg ha^{-1} (GOI, 2015). National statistics clearly indicated that area of arecanut exhibited an upward trend over time, but the productivity showed stagnant trend during last decade. The productivity of arecanut (kg ha^{-1}) fluctuated from 857 in 1970 to 1379 in 2002 and 1195 in 2012. Though area and production of cocoa showed upward trend, productivity fluctuated registering stagnant trend. These plantation crops have high economic value and provide sustenance to the millions of people in India. The low productivity of arecanut and cocoa is due to climatic, crop and soil constraints and strategies are developed to improve productivity. As perennial plantations remain productive for several decades, weather variability influences the yield. But the studies on the impact of climate change on arecanut and cocoa are scarce in India. With this background, an attempt was made in this chapter to assess overall changes in weather pattern in humid tropics and its impending influence on productivity of arecanut and cocoa based on data acquisition from published reports. Further, other reports are also discussed.

2. Climatic Conditions in Plantation Belt

The parameters like heavy rainfall, high relative humidity and low temperatures are the major climatic constraints in arecanut and cocoa growing regions of humid tropics. In other regions, low rainfall and high temperatures are the major problems. Heavy rainfall leads to leaching of potassium and calcium and high relative humidity is congenial for proliferation of pests and diseases. Low temperatures at high altitude areas lead to softness of kernel and low nut recovery. Untimely rains and heavy rainfall events are commonly noticed in all arecanut growing regions. The resource use efficiency reduces considerably due to water stagnation, run off, soil erosion and leaching of nutrients due to heavy rainfall events in laterite soil belt of humid regions especially in areas undulating topography. Drought results in yield loss of 15-75 per cent (Bhat and Sujatha, 2004). Heavy rainfall events inflict a yield loss up to 90 per cent due to fruit rot (Jose *et al.*, 2008; CPCRI, 2015). This emphasizes the need for thorough understanding of impact of climate change in order to streamline the adaptation strategies for sustainability of perennial plantations.

2.1. Suitable Climate for Arecanut

Arecanut is grown in varied climatic conditions. However, it is sensitive to extreme climatic conditions (Bhat and Abdul Khader, 1982). In general, climate influences the yield to the extent of 50 per cent. The crop is grown within 28° North and South of equator. The rainfall, relative humidity, altitude, evaporation and temperature affect the yield of arecanut (Vijaya Kumar *et al.*, 1991; Sunil *et al.*, 2011). The lower temperature at higher elevation is unsuitable for arecanut. In north east region of India the crop is grown in plains. Even though the crop can be grown at altitudes of 1000 masl, it is seen that the quality of the nut deteriorates as altitude increases (Nambiar, 1949).

The temperature range of 14°C-36°C is optimum for better growth of arecanut. In India, the crop is being grown in temperatures ranging from 5°C (as in places like Mohitnagar, West Bengal) and at 40°C (Vittal in Karnataka and Kannara in Kerala). The temperature below -2.8°C caused damage to foliage and even death of palms (Smith, 1958). Severe foliar damage is noticed at low temperature with low humidity (Bhat and Sujatha, 2004). The extremes of temperature and wide diurnal variations are detrimental to growth of the crop. Increase in minimum temperature during flowering stage (January to March) has positive influence on arecanut yield (Sunil *et al.*, 2011). Arecanut is grown in high rainfall areas such as Malnad of Karnataka (≥ 4500 mm) and in low rainfall areas like plains of Karnataka or parts of Coimbatore district in Tamil Nadu (750 mm). Higher rainfall during nut development stage (June to July) reduces the yield. Annual rainfall above 2000 mm has detrimental effect on arecanut yield, while this crop needs higher relative humidity during the morning hours throughout the year (Sunil *et al.*, 2011). High humid conditions provide congenial conditions for the rapid spread of diseases like fruit rot, bud rot etc. It has considerable influence on evapotranspiration hence on the water requirement of arecanut. Thus, climate change scenario would influence growth and yield of arecanut.

2.2. Suitable Climate for Cocoa

Cocoa is a major cash crop in many tropical countries, where the climate shows relatively little variation throughout the year, especially in terms of temperature, solar radiation and day length. Seasonal variations in both rainfall and temperature influence the pod setting. The microclimate existing in arecanut and coconut plantations is congenial for cocoa cultivation in India. In rainfed coconut gardens, the drought intensity is more pronounced in northern regions of Kerala and coastal Karnataka extending up to 5-6 months subjecting cocoa to severe stress. The situation is better in arecanut gardens, which is an irrigated crop.

For cocoa, the distribution of rainfall is more important than total rainfall. Intensity and distribution of rainfall decide the pattern of cropping in mature cocoa. Two dissimilar crop patterns are observed under rainfed and irrigated conditions in India. The annual rainfall in most of the cocoa growing areas lies between 1,250 and 3,600 mm. If rainfall is less than 1,250 mm, the crop needs to be irrigated during the rainless period. High rainfall in excess of 2,500 mm may lead to problems such as black pod disease due to high humidity. Cocoa growing areas have uniformly high humidity, often 100 per cent during night falling to 70-80 per cent by day.

Cocoa can be successfully grown up to 300 masl. However, it can be grown up to 1100-1200 m altitude. Cocoa can tolerate a mean monthly maximum temperature up to 33°C and the optimum range is 30-32°C. The temperature in most of the cocoa growing areas lies between a maximum of 30-32°C and a minimum of 18-21°C. Low temperatures have an inhibiting effect on cambium growth, which is linked to flowering. High temperature reduces the pod growing period and in turn the yield and bean size. Thus, the impact of climate change will be severe on cocoa. In West Africa, Brazil, other Latin American countries, Malaysia and Sri Lanka high correlations between rainfall and yield have been reported. Other climatic factors such as temperature, light intensity and day length normally are not limiting factors for cocoa yields except in Brazil which experiences nearly four months of low temperature during winter.

2.3. Data Acquisition

The weather data of 43 years recorded at ICAR-Central Plantation Crops Research Institute, Regional Station, Vittal, Karnataka, India (12° 15′N latitude and 75° 25′E longitude, 91 m above MSL) is utilized for assessing the impact of climate change on arecanut and cocoa. The climate of the location is humid tropical with average annual rainfall of 3686 mm. The yield data of arecanut and cocoa were collected from records of different experiments in arecanut and cocoa at the Institute. For computing average yield of arecanut in different years, data acquisition was attempted from the published reports of ICAR-CPCRI (CPCRI, 1996; Bhat and Mohapatra, 1989; Balasimha, 2007; Balasimha, 2009; Bhat *et al.*, 1999; Sujatha *et al.*, 1999; Bhat *et al.*, 2007a; Sujatha *et al.*, 2010; Sujatha *et al.*, 2011a; Sujatha and Bhat, 2013a and b). The average yield for a particular year was computed from all the records to nullify treatment or technology effect as technological and resource constraints are likely to limit productivity (Mendelsohn and Dinar, 2003).

2.3.1. Time Trend of Weather Variables in Coastal Humid Tropics

The descriptive statistics of weather variables at Vittal is given in Table 4.1. The normal weather variable was taken as the average of last 43 years. The changes in weather variables during 2000-2012 compared to previous years are given in Table 4.2. Precipitation trends indicated very low variability for total rainfall and rainy days among different years. Inter-annual variability of rainfall is generally large in the tropics.For the period 1970–2012, the mean annual precipitation is 3686 mm and ranges from 2114 mm in 1987 to 5610 mm in 1994. The total rainfall (RF) decreased by 531 mm *i.e.*, 14 per cent during 2000-2012 compared to 1970-1999. With respect to air temperature (T) changes, years explained higher variability for T_{max} (33 per cent) than T_{min} (9 per cent). The trends of temperature increase are +0.4°C for mean maximum ($P < 0.001$) and + 0.4°C for mean minimum during the last decade ($P < 0.002$). Thus, for the 43-year period, the observed difference between maximum and minimum is +0.8°C. Years explained 36 and 6 per cent variability in relative humidity (RH) at 7.30 and 14.20 hrs, respectively. The RH at morning time increased, while RH at afternoon reduced during the observed period. Years showed maximum variability for number of sunshine hours per day (66 per cent) and pan evaporation (43 per cent) among all weather parameters. Both sunshine (SS) hrs and pan evaporation reduced during 2000-2012 compared to preceding years.

Table 4.1: Descriptive Statistics of Weather Variables Averaged for 1970-2012 in Humid Tropics at Vittal

Variable	*Mean*	*Minimum*	*Maximum*	*Std. Deviation*
Annual rainfall (mm)	3686± 95	2113	5610	624
Maximum temperature (°C)	32.4 ±0.06	31.2	33.2	0.42
Minimum temperature (°C)	22.0±0.06	21.2	22.8	0.37
Rainy days	139 ± 2.04	111	165	13.4
RH at 7.30 hrs	93.8 ±0.17	91.3	96.1	1.10
RH at 14.20 hrs	60.8 ±0.28	57.1	64.7	1.87
Sunshine hours	6.6 ±0.10	5.1	7.6	0.67
Evaporation (mm)	4.0 ±0.08	3.1	5.0	0.54

Table 4.2: Weather Variability during 1970-2012

Variable	*1970-99*	*2000-2012*	*Change in 2000-2012 Over 1970-99*
Minimum temperature	22.2	21.8	+ 0.4
Maximum temperatute	32.3	32.7	+ 0.4
RH at 7.30 hrs	93.5	94.5	+ 1.0
RH at 14.20 hrs	60.8	60.8	–
Sun shine hours	6.9	6.1	– 0.8
Evaporation	4.3	3.7	– 0.6
Total Rainfall	3846	3315	– 531
Total rainy days	141	134	– 7

2.3.2. Relation between Yield of Arecanut/Cocoa and Weather Variables

Positive and significant correlations are observed between arecanut yield and weather variables such as T_{max} (r=0.48), T_{min} (r=0.16) and RH (r=0.32 to 0.49) (Table 4.3). Negative correlations are noticed between arecanut yield and rainfall/sunshine hours (r = -0.20 to -0.21), while no relation is observed for evaporation and rainy days. Simple correlations showed that kernel yield is more closely related to RH and T_{max} than T_{min}, SS hrs and RF (Table 3).Significant positive impact of SS hrs, PE, T_{min} and RF on dry bean yield of cocoa is noticed (Table 3), while correlations are negative for T_{max} and $RH_{forenoon}$.

2.3.3. Weather Variability and Impact on Arecanut and Cocoa

Perennial systems are slow to adapt and more vulnerable to climate change (Rosenzweig and Hillel, 1998; Burton and Lim, 2005).Botharecanut and cocoa are perennial in nature with high commercial value. Thus, climate change will have

Table 4.3: Correlation between Yield and Weather Variables

Variable	*Arecanut*	*Cocoa*
Minimum temperature	0.16*	0.30*
Maximum temperatute	0.48**	–0.14*
RH at 7.30 hrs	0.32**	–0.30*
RH at 14.20 hrs	0.49**	–0.02
Sun shine hours	–0.21*	0.42**
Evaporation	–0.05	0.37**
Total Rainfall	–0.20*	0.13*
Total rainy days	0.00	0.08

agronomic impacts on yields and also generate economic effects on prices, demand and trade. Despite development of efficient technologies, the productivity levels remained more or less stagnant during 1990-2010. This explains the influence of climate on yield. The significant relation of weather parameters with yield further substantiates the impact of weather (Table 4.3). The yield reduction might be due to reduced recovery and changes in phenology. The changes in weather variables might influence net photosynthesis, evapotranspiration, flowering, pollination and yield. Several reports indicated similar impact of weather changes on several crops (White *et al.*, 1999; Kramer *et al.*, 2000; Chuine *et al.*, 1999) and in cocoa (Joly and Hahn 1989; Balasimha *et al.*, 1991). In many cases, high precipitation is associated with a reduction in yields due to reduced pollination and increased incidence of diseases in wetter years. High rainfall (5610 mm in 1994) with high intensity rains results in spread of fruit rot (*Phytophthora palmivora*) and water stagnation leading to yield reduction in arecanut (CPCRI, 1996; Sujatha *et al.*, 1999). In 2007, the yield loss of 40 per cent is reported in arecanut due to continuous rainfall of >2500 mm in July-September, high RH and less sunshine hrs (Jose *et al.*, 2009). The results give indication that continuous and heavy rainfall as in July (>1000 mm) is not ideal for arecanut as it creates waterlogging, higher incidence of *Phytophthora* diseases and hampers pollination/nut development. The emergence of two new pests *viz.*, palm aphid and whitefly in arecanut is a consequence of either climate change or pest resurgence in perennial ecosystem (Joseph Rajkumar, 2013). The variations in rainfall from May to November and relative humidity at afternoon hours significantly affect the arecanut yield in Western Ghat region of Karnataka (Tejaswani *et al.*, 2014). Results of survey in South Konkan region of Maharashtra revealed that arecanut yield is directly proportional to rainfall above 4300 mm with maximum humidity (Salvi *et al.*, 2015) and arecanut prefers high relative humidity particularly during morning hours throughout its growth period.

The impact of rainfall on incidence of black pod disease is not visible in cocoa as pod development stage escapes high monsoon rainfall in humid tropics of India. However, cocoa production is reduced by 15-20 per cent in Nigeria in 2011 due to high rainfall and inability of the farmers to buy chemicals to combat black pod disease (Oredein, 2011). Lawal and Emaku (2007) analyzed the impact of climate change on cocoa production at the Cocoa Research Institute of Nigeria (CRIN) between 1985 to 2004 and stated that the standard deviation of cocoa output is 4.69. Further, it is stated that increase in temperature enhances cocoa production and increase in relative humidity decreases it. Oyekele (2012) stated that the sensitivity of cocoa production to hours of sunshine, rainfall, soil conditions and temperature makes it vulnerable to climatic change. Changing climate can also alter the development of pests and diseases and modify the host's resistance. Further, it is reported that the black pod disease is a major threat to cocoa production when the relative humidity is very high.

2.3.4. Differential Response of Arecanut and Cocoa

Attainable yield is mainly limited by water or nutrient supply (van Ittersum and Rabbinge, 1997; Stewart *et al.*, 2005). The results indicate that the cocoa is more affected by climate variability than arecanut. This might be due to conspicuous changes in phenology and increased incidence of pests and diseases like tea mosquito bug,mealy bug andblack pod (Personal communication). Both arecanut and cocoa are highly cross pollinated and thus weather variability might influence phenology. On an average, infestation of tea mosquito bug is about 25 per cent in cocoa during the last decade. The incidence of black pod disease ranges from 6 to 51 per cent during monsoon season.

Zuidema *et al.* (2005) stated that over 70 per cent of the variation in simulated bean yield in cocoa could be explained by a combination of annual radiation and rainfall during the two driest months. Similar relations are observed in this study between cocoa dry bean yield and weather. The cumulative effect of changes in temperature, rainfall, humidity, evaporation, and sunshine hours has impact on the yield of cocoa.

The correlations between yield and weather parameters clearly indicate differential response of arecanut and cocoa (Table 4.3). The rainfall has negative impact on arecanut and positive impact on cocoa, which might be due to differences in yielding pattern. The nut development stage in arecanut invariably faces heavy rains resulting in yield loss due to water stagnation, pests and diseases, but cocoa escapes heavy monsoon rains during pod development stage. Another significant aspect of variability is sunshine hours showing negative impact on arecanut and positive impact on cocoa (Table 4.3). As cocoa is a shade crop in arecanut plantations with only 40 per cent of the incident radiation reaching the ground (Muralidharan, 1990), the positive relation between yield and sunshine hours indicates the need for higher sunlight availability to cocoa. Cocoa exhibits increased production under lowered light levels with optimal growth at 20to 30 per cent of full sunlight (Okali and Owusu, 1975; Galyuon *et al.*, 1996).Similarly, positive response of arecanut and negative response of cocoa to $RH_{forenoon}$ can be attributed to increased microclimatic humidity in arecanut plantation over atmospheric humidity.

Both arecanut and cocoa have similar evaporative demand in humid tropics (Abdul Haris *et al.*, 1999; Bhat *et al.*, 2007a), but the response of cocoa to pan evaporation was positive and significant. Reduced evaporation in recent years might impact the transpiration losses through metabolic activities of these crops and in turn the productivity. Model simulations of the potential yield of tea in north-east India predicted slight reduction in yield for each mm reduction in evapotranspiration (Panda *et al.*, 2003). The sensitivity of cocoa to T_{max} and positive response of arecanut clearly explains the shade requirement of cocoa ruling out the possibility of sole cropping of cocoa in humid tropics. Minimum temperature has shown positive impact on both crops suggesting clear adaptability of these crops. There is no influence of rainy days on both crops clearly indicating that the intensity and distribution of rainfall are important. The impact of weather variability on growth and yield would be different for dicot and monocot perennials.Even though simulation model in perennial crop like cocoa (Zuidema *et al.*, 2003) has been reported, the model is not yet validated for Indian conditions and suitability for climate change studies.

3. Adaptation Strategies

Crop management needs to fine-tune to weather changes as an adaptation strategy. Identification of genotypes tolerant to various biotic and abiotic stresses is need of the hour. During 2000-2015, successful technologies like nutrient and irrigation management (Bhat and Sujatha, 2004), drip fertigation (Bhat *et al.*, 2007a; Sujatha and Bhat, 2013a), cropping systems (Bhat and Sujatha, 2011; Sujatha *et al.*, 2011b; Sujatha *et al.*, 2016) and mixed farming approach (Sujatha and Bhat, 2015) in arecanut reduced the impact of weather changes (Table 4). Drip fertigation is a better adaptation strategy under changing climate scenario in humid tropics as it sustains yield levels in low rainfall years also as in 2002and 2012 (Bhat *et al.*, 2007a; Sujatha and Bhat, 2013a). In 2002, yield loss of 13 -14.5 per cent is reported in farmer's plantations due to less rainfall (Jose *et al.*, 2004). Adoption of farming systems is necessary to reduce income fluctuations due to weather changes (Sujatha and Bhat, 2015b). The predominant arecanut belt in India is laterite soil belt in humid tropics that receives higher average rainfall of above 3500 mm. Still water scarcity is noticed during summer months due to inherent soil constraints, higher evaporative demand of arecanut and faster depletion of ground water levels and less water harvesting possibilities (Mathew *et al.*, 2004 and 2008). The yield gap of 120-180 per cent between national/state average and on-station experiments clearly indicates that the adoption of these suitable technologies can be a better adaptation strategy under climate change scenario.The efficient arecanut based cropping system models for adaptation to climate change are given in Table 4.4. However, the scope for improving the productivity of arecanut by 200 to 300 per cent and profitability is demonstrated through different technologies at ICAR-CPCRI.

Coastal and hilly areas, where plantations are concentrated, are believed to be more vulnerable to climate change compared to other terrestrial areas. Thus, soil and water conservation incorporating concepts of water harvesting, *in situ* moisture conservation, life saving irrigation, mulching, permanent crop cover, ground water recharge through run off water ways, watershed management and erosion control measures attain utmost importance as climate change projects increase in frequency of extreme events. Adaption of cropping system and integrated farming approaches is very important for combating the risks of monocropping and climate change (Sujatha and Bhat, 2015; Sujatha *et al.*, 2016).

Table 4.4: Yield Gap between National Productivity and different Technologies

Suitable Adaptation Strategy	*Yield Level ($kg\ ha^{-1}$)*	*Yield Gap (per cent) between Strategy and National Average Yield (1600 $kg\ ha^{-1}$)*	*Reference*
Drip fertigation (2002-2006)	4017	151	Bhat *et al.*, 2007a;
Organic matter recycling (2003-2011)	2774	73	Sujatha and Bhat, 2013b; Sujatha and Bhat, 2016
Cropping system approach			
Arecanut+MAPs with sprinkler irrigation (2004-2007)	3010	88	Sujatha *et al.*, 2011a
Arecanut+vanilla with drip irrigation (2005-2008)	3114	95	Sujatha and Bhat 2010
Arecanut+cocoa with drip fertigation (2008-2011)	3117	95	Sujatha and Bhat 2013a
Mixed farming approach (2012-2014)	3418	114	Sujatha and Bhat, 2015

For reducing the climate change impact at regional levels, attempt should be made to adopt good agricultural practices like minimum tillage, drip fertigation, reduced input use, eco-friendly management of pests and diseases, and recycling of organic wastes to reduce emissions of GHG's especially CO_2.

4. Arecanut and Cocoa for Carbon Sequestration

Plantation crops have significant potential for offsetting and reducing the projected increases in green house gas (GHG) emissions and regarded as an important option for greenhouse gases mitigation. Plantation crops are generally cultivated in contiguous areas and can sequester considerable carbon due to higher growth and biomass increments. The plantation crops occupy the land for more than 3 decades and accumulate both above ground and below ground root stocks in this process. The reports indicate that the carbon sequestration potential of arecanut with and without the presence of inter/mixed crops is very high and are comparable to forests (Balasimha and Naresh Kumar, 2010). Annual increments in biomass or net primary productivity ranged from 3.34 -7.11 t ha^{-1} in arecanut. In arecanut, annual increment in carbon stock is 1.4-3.0 t ha^{-1}(Balasimha and Naresh Kumar, 2009). Arecanut-cocoa also is a good system for carbon sequestration with a potential to sequester 5 to 7 t CO_2/ha/year (Balasimha and Naresh Kumar, 2009). 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 (Figure 4.1). Recent estimates indicated that the total carbon stocks vary from 129 to 169 t ha^{-1} in arecanut plantations of different ages (Sujatha and Bhat, 2015b). Further, soil carbon stocks (119-137 t ha^{-1}) are higher than standing above ground carbon stocks (10-21 t ha^{-1}) at 0-30 cm soil depth. The soil organic carbon levels are optimum in arecanut ecosystem Soil carbon stocks account for 80 per cent of carbon stocks in arecanut and mixed farming approach is the best

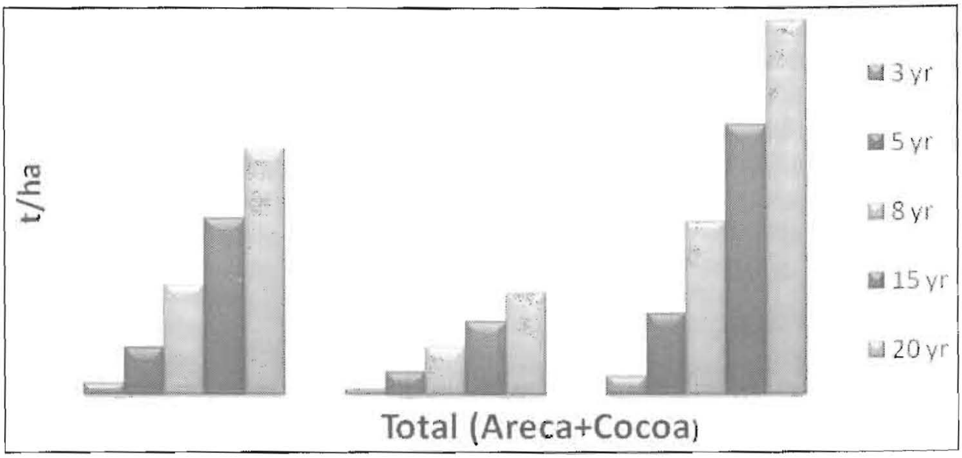

Figure 4.1: Carbon Sequestration in Areca and Cocoa System.

option for climate change scenario due to recycling of critical inputs among crop and livestock components (Sujatha and Bhat, 2015). Thus, carbon stocks in biomass and soil organic matter result in the net removal of CO_2 from the atmosphere.

5. Conclusions

The results imply that weather has a definite role in influencing the yield of arecanut and cocoa. A comprehensive analysis of 43-yr weather data from 1970-2012 revealed that humidity and temperature increase, while other variables like total rainfall, sunshine hours and evaporation decrease in humid tropics in India. The correlations between weather variables and yield was either positive or negative or without any relation. There was differential response of arecanut and cocoa to weather variability. The suitable adaptation strategies are also discussed for these two crops.The crop productivity remains highly dependent on weather, which can affect boththe quantity and quality,despite advances in technology and the widespread prevalence of irrigation facilities in arecanut belt due to climate change.

References

Abdul Haris, A., Balasimha, D., Sujatha, S., Bhat Ravi, Khader, K.B.A. (1999). The influence of drip irrigation and fertilizer on yield and photosynthetic characteristics of cocoa in mixed cropping system with arecanut. *J. Plantation Crops* 27, 131-135

Balasimha, D. and Naresh Kumar, S. (2013). Net primary productivity, carbon sequestration and carbon stocks in areca-cocoa mixed crop system. *Journal of Plantation Crops.* 41(1): 8-13.

Balasimha, D. (2007). Efficacy of pruning in enhancing bean yield of cocoa. *J. Plantation Crops* 35, 201-202.

Balasimha, D. (2009). Effect of spacing and pruning regimes on photosynthetic characteristics and yield of cocoa in mixed cropping with arecanut. *J. Plantation Crops* 37(1), 9-14.

Balasimha, D., Daniel, E.V., Bhat, P.G. (1991). Influence of environmental factors on photosynthesis in cocoa trees. *Agric. Forest Meteorol.* 55, 15-21.

Bhat, K. S. and Abdul Khader, K. B. (1982). Crop Management. B. Agronomy. In: *The Arecanut Palm.* (Eds. Bavappa, K.V.A., Nair, M.K. and Prem Kumar, T.). CPCRI, Kasaragod. pp 105-131.

Bhat Ravi, Reddy, V.M., Khader, K.B.A. (1999). Areca based high density multispecies cropping system in coastal Karnataka. *J. Plantation Crops*27(1), 22-26.

Bhat Ravi, Sujatha, S., Balasimha, D. (2007). Impact of drip fertigation on productivity of arecanut (*Areca catechu* L.). *Agric. Water Manage.* 90, 101-111.

Bhat, N. T., Mohapatra, A. R. (1989). Effect of supplying nutrients through organic manures, inorganic fertilisers and their combination on arecanut crop. *J. Plantation Crops*16 (Suppl), 443-447.

Bhat, Ravi and Sujatha, S. (2004). Crop Management. In: Balasimha, D., Rajagopal, V. (Eds.), Arecanut. CPCRI, Kasaragod. pp. 76-102.

Bhat, Ravi and Sujatha, S. (2011). Arecanut based high density multispecies cropping/ farming system. In: Thomas, G.V., Krishnakumar, V., Maheshwarappa, H.P., Bhat, R., Balasimha, D. (Eds.), Arecanut based cropping/farming systems. CPCRI, Kasaragod. pp. 27-44.

Burton, I., Lim, B. (2005). Achieving adequate adaptation in agriculture. *Clim. Change* 70, 191–200.

Chmielewski, F.-M., Rötzer, T. (2001). Response of tree phenology to climate change across Europe. *Agric. Forest Meteorol.* 108, 101–112,

Chuine, I., Cour, P., Rousseau, D.D. (1999). Selecting models to predict the timing of flowering of temperate trees: implication for tree phenology modelling. *Plant Cell Environ.* 22, 1–13.

CPCRI, 2015. Annual Report for 2014-2015. Central Plantation Crops Research Institute, Kasaragod, India.

CPCRI. (1996). Central Plantation Crops Research Institute, Annual Report for 1995-96, Kasaragod. pp. 220.

Galyuon, I.K.A., McDavid, F.B., Lopez, F.B., Spence, J.A. (1996). The effect of irradiance level on cocoa (*Theobroma cacao* L.): 1. Growth and leaf adaptations. Trop. Agric. (Trinidad) 73, 23–28.

GOI. (2015). Agricultural Statistics at a Glance, Directorate of Economics and Statistics, Ministry of Agriculture, Govt of India, New Delhi.

Joly, R. J., Hahn, D.T. (1989). Net CO2 assimilation of cocoa seedlings during periods of plant water deficit. *Photosynth.* Res. 21, 151-159.

Jose C.T., Balasimha, D., Kannan, C. (2009). Yield loss due to fruit rot disease in Karnataka. *Indian J. Arecanut, Spices and Med. Plants* 10, 45-51.

Jose, C. T. Jayashekar, S., Balasimha, D. (2004). Impact of drought on arecanut in Karnataka. *Indian J. Arecanut, Spices and Medicinal Plants* 5 (4), 144-149.

Josephrajkumar, A., Rajan, P., Chandrika Mohan, Nampoothiri, C.G.N. (2013). Distinguishing palm aphid and arecanut whitefly, two emerging pests in palms. *Indian J. Arecanut, Spices and Medicinal plants* 15 (2), 3-7.

Kramer, K., Leinonen, I., Loustau, D. (2000). The importance of phenology for the evaluation of impact of climate change on growth of boreal, temperate and Mediterranean forest ecosystems: an overview. *Int. J. Biometeorol.* 44, 67–75.

Lawal, J.O. and Emaku, L. A. (2007). Evaluation of the effect of climatic changes on cocoa production in Nigeria: Cocoa Research Institute of Nigeria (CRIN) as a case study. *African Crop Science Conference Proceedings*, 8, 423 – 426.

Mathew, A. C., Shajatnan, K. H., Sujatha, S. (2004). Water movement in the active root zone of arecanut under drip irrigation. *J. Plantation Crops* 32(Supplement), 248-252.

Mathew, A. C., Shajatnan, K. H., Sujatha, S. (2008). Development and Management of water harvesting structure in laterite soils for irrigating arecanut through conjunctive use of harvested and surface water. *J. Plantation Crops* 36(3), 304-309.

Mendelsohn, R., Dinar, A. (2003). Climate, water, and agriculture. Land Econ. 79:328–341.

Muralidharan, A. (1990). Intercropping in arecanut. *J. Plantation Crops*17, 25-38.

Nambiar, K. K. (1949). *A Survey of Arecanut Crops in Indian Union*. Indian Central Arecanut Committee, Calicut. pp 76.

Nellemann, C., MacDevette, M., Manders, T., Eickhout, B., Svihus, B., Prins, A. (2009). The environmental food crisis: the environment's role in averting future food crises. United Nations Environment Programme.

Nelson, G.C., Rosegrant, M.W., Koo, J., Robertson, R., Sulser, T., Zhu, T., Ringler, C., Msang, S., Palazzo, A., Batka, M., Magalhaes, M., Valmonte-Santos, R., Ewing, M., Lee, D. (2009). Climate change: impact on agriculture and costs of adaptation. Technical report, International Food Policy Research Institute.

Okali, D.H.H., Owusu, J.K. (1975). Growth analysis and photosynthetic rates of cocoa (*Theobroma cacao* L.) seedlings in relation to varying shade and nutrient regimes. *Ghana J. Agric.* Sci.8, 51-67.

Oredein O. (2011). Nigeria's cocoa output estimated 15 per cent -20 per cent lower. Market Watch –The Wall Street Journal. Internet file downloaded on 10thJanuary 2012 from http://www.marketwatch.com/story/nigerias-cocoa-output-estimated-15-20-lower-2011-07-29.

Oyekale A S. (2012). Impact of Climate Change on Cocoa Agriculture and Technical Efficiency of Cocoa Farmers in South-West Nigeria. *J Hum Ecol*, 40(2): 143-148.

Panda, R. K., Stephens, W. and Matthews, R. (2003). Modelling the influence of irrigation on the potential yield of tea (*Camellia sinensis*) in North-East India. *Experimental Agriculture.*

Rosenzweig, C., Hillel, D. (1998). Climate Change and the Global Harvest. Oxford University Press, New York, 324 pp.

Salvi, S. P., Mule, R. S., Agare, H. R.,(2015). Survey on yield of arecanut (*Areca catechu* L.) influence with weather parameters under South Konkan region of Maharashtra. *Indian J. Arecanut, Spices and Medicinal plants* 17(4), 38-40.

Smith, D. (1958). Cold tolerance of cultivated palms. *Principes.* 2:120.

Sujatha, S. and Bhat Ravi, (2010). Response of vanilla (*Vanilla planifolia* A.) intercropped in arecanut to irrigation and nutrition in humid tropics of India. *Agric. Water Manage.* 97(7), 988 - 994.

Sujatha, S. and Bhat Ravi, (2013a). Impact of drip fertigation on arecanut–cocoa system in humid tropics of India. *Agroforest. Syst.*87(3): 643-656.

Sujatha, S. and Bhat Ravi, (2013b).Impact of vermicompost and NPK application on biomass partitioning, nutrient uptake and productivity of arecanut (*Areca catechu* L.). *J. Plant Nutr.* 36(06); 975-988.

Sujatha, S. and Bhat. Ravi. (2015). Resource use and benefits of mixed farming approach in arecanut ecosystem in India. *Agr. Syst.* 141, 126-137.

Sujatha, S., Bhat Ravi and Chowdappa, P. (2016). Cropping systems approach for improving resource use in arecanut (*Areca catechu*) plantation. *Indian Journal of Agricultural Sciences* **86** (9): 1113–20.

Sujatha, S., Bhat Ravi, Kannan, C., Balasimha, D. (2011a). Impact of intercropping of medicinal and aromatic plants with organic farming approach on resource use efficiency in arecanut (*Areca catechu* L.) plantation in India. *Ind. Crops Prod.* 33(1), 78-83.

Sujatha, S., Bhat Ravi, Reddy, V.M., Abdul Haris, A. (1999). Response of high yielding varieties of arecanut to fertilizer levels in coastal Karnataka. *J. Plantation Crops* 27, 187-192.

Sujatha, S., Bhat. Ravi, Balasimha, D. and Apshara, E. S. (2011b). Arecanut based inter/mixed cropping systems. In: Thomas, G.V., Krishnakumar, V., Maheshwarappa, H.P., Bhat, R., Balasimha, D. (Eds.), Arecanut based cropping/farming systems. CPCRI, Kasaragod. pp. 6-26.

Sunil, K.M., Devadas, V.S. and George, P.S. (2011). Influence of Weather Parameters on Yield and Yield Attributes of Areca Nut (*Areca catechu* L.). *Journal of Agricultural Physics.* 11:88-90.

Tejaswini, A.B., Padmashri, H.S., Soumya, D.V., Kammardi, T.P., Hemalatha, H.G. (2014). Association studies of climate factors on arecanut yield in Western Ghats region Karnataka. *Environ. Ecol.*32(3A), 1085-1087.

van Ittersum, M.K., Rabbinge, R. (1997). Concepts in production ecology for analysis and quantification of agricultural input-output combinations. Field Crops Res. 52, 197-208..

Vijaya Kumar, B. G., Veerappadevaru, G., Balasimha, D., Abdul Khader, K. B. and Ranganna, G. (1991). Influence of weather on arecanut and cocoa yield. *J. Plantn. Crops.*19: 33-36

White, M.A., Running, S.W., Thornton, P.E. (1999). The impact of growing-season length variability on carbon assimilation and evapotranspiration over 88 years in the eastern US deciduous forest. *Int. J. Biometeorol.* 42, 139–145.

Zuidema, P.A., Leffelaar, P.A., Gerritsma, W., Mommer, L., Anten, N.P.R. (2005). A physiological production model for cocoa (Theobroma cacao): model presentation, validation and application. *Agric. Syst.* 84, 195–225.