

Chapter 2

Coconut

*S. Naresh Kumar, V. John Sunoj, K.S. Muralikrishna,
K.B. Hebbar, V. Rajagopal, K.V. Kasturi Bai
and P. Chowdappa*

1. Causes of Climate change

Over exploitation of fossil fuels, deforestation, land use change and energy use inefficient technologies have led to rapid accumulation of greenhouse gases (GHGs) in the atmosphere. The CO₂ concentration has increased from a pre-industrial value of about 280 ppm to 401 ppm in 2016. Similarly, the global atmospheric concentration of methane and nitrous oxides and other GHGs has also increased considerably. In addition, globally about 190 Mt of urea is used in agriculture. As a consequence emission of N₂O from agricultural fields led to rise in the atmospheric concentration of N₂O. Since the life-time of the CO₂, methane and N₂O are about 120, 10 and 150 years, respectively, past and current emissions continue to warm the climate and cause climate change even if GHG emissions are reduced. 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" (United Nations Framework Convention on Climate Change (UNFCCC)). The UNFCCC thus makes a distinction between "climate change" attributable to human activities altering the atmospheric composition, and "climate variability" attributable to natural causes.

2. Past Trends in Global and Indian Climate

The global mean temperatures during 1951-2010 period increased by 0.6-0.7°C out of which natural variability contributed to ±0.1°C change in temperature (IPCC, 2013, 2014). This indicated that the anthropogenic rise in temperature is about 0.6°C during 1951-2010 period. In Indian region, annual mean maximum

temperatures increased by about 0.71°C in past 100 years. The rate of increase in temperature enhanced and in post 1970's the warming has been at a rate of $0.17^{\circ}\text{C}/10$ years. Similarly, the minimum temperature has been rising at a rate of $0.29^{\circ}\text{C}/10$ years (IITM, 2011). Rise in temperatures alter the hydrological cycle and thus the precipitation. Since 1871, India faced 28 deficit and 20 excess monsoon years and out of these, as many as 16 deficit monsoon years and 6 excess monsoon years fell in post 1960 period.

3. Projected Climate Change Scenarios

Increase in atmospheric concentration of GHGs vary depending upon the current and future developmental pathways. For instance, rapid economic growth without due consideration for environmental protection will lead to unabated accumulation of GHGs in atmosphere. These GHGs can cause the warming of 8.5 W.m^{-2} (this scenario is called representation concentration pathway 8.5 -RCP 8.5). This will lead to a very high increase in global temperatures and disturbances in hydrological cycle and thus precipitation. On the other hand, eco-friendly technologies and environment-friendly developmental strategies will have least accumulation of GHGs in atmosphere leading to not so much warming (about 2.6 W.m^{-2} -RCP 2.6).

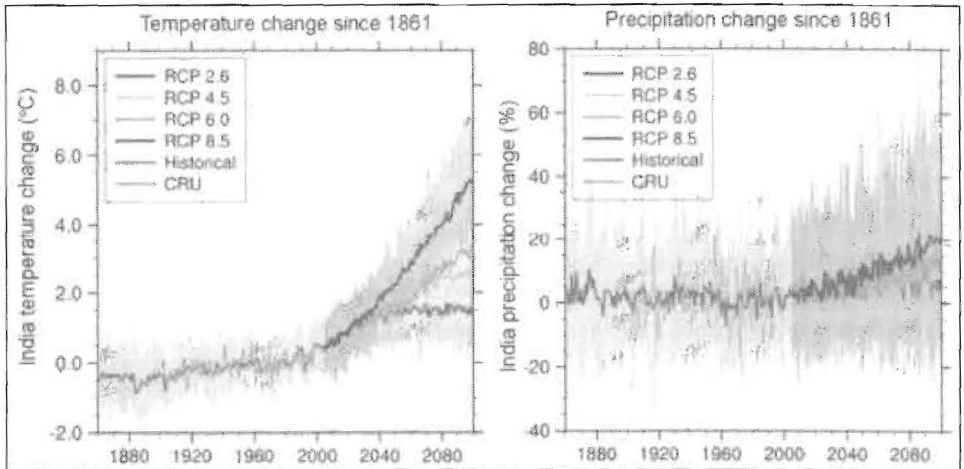


Figure 2.1: Projected Change in Mean Annual Temperature and Precipitation Over India in different Climate Scenarios (Source: Chaturvedi *et al.*, 2012).

Future climatic scenarios are simulated using the global climate models (GCMs) and regional climate models (RCMs). More than 56 GCMs project an increase of global mean surface temperatures in the range of 0.3°C to 1.7°C (RCP 2.6), 1.1°C to 2.6°C (RCP 4.5), 1.4°C to 3.1°C (RCP 6.0), 2.6°C to 4.8°C (RCP 8.5) for 2081–2100 relative to 1986–2005 period (Figure 2.1). The projected increase in temperature for south Asia is in the range of 0.5 to 1.2°C by 2020, 0.88 to 3.16°C by 2050 and 1.56 to 5.44°C by 2080, depending on the scenario of future development. Further, the IPCC AR5 (2014) on climate change has projected an increase in the frequency of droughts, floods, and extreme events of temperature and rainfall. The report also

projected an increase in the area encompassed by the monsoon phenomena. These climatic changes further increase the pressures on Indian agriculture including plantation crops.

4. Climatic Change and Agriculture

Plant growth, development and yield are highly influenced by the climatic factors apart from other environmental factors. Among many climatic factors that influence crop performance temperature, rainfall, CO₂ and light are the most important. Temperatures influence the growth rates and high temperatures affect photosynthesis (Blum *et al.*, 1994; Hatfield and Prueger, 2015) growth and development, shorten growth period (Porter and Gawith, 1999), affect sink parameters (Hatfield and Prueger, JH (2015) and thus yield (Assange *et al.*, 2010, Naresh Kumar *et al.*, 2013, 2014 a and b). Similarly very low temperatures cause tissue damage, slow metabolic rates and affect the growth, development and yield of the plants.

Projected increase in frequent droughts and heavy precipitation events in future climates means plants will be exposed to multiple stresses even in a single season (Naresh Kumar *et al.*, 2012). Impacts of water stress range from cell water potential loss to leaf and plant wilting causing severe loss to yield as a consequence of reduced photosynthesis, growth and canopy area. Similarly the excess light causes photo-oxidative stress damaging cell membrane resulting in leaf scorching and plant death (Naresh Kumar and Kasturi Bai, 2009). However, increase in atmospheric CO₂ can be beneficial to plant photosynthesis, particularly in C3 plants (Ainsworth and Long, 2005; Kimball *et al.*, 1995, 2002). Though, elevated CO₂ may not benefit C4 plants in normal management conditions, but under water stressed conditions, it indirectly increases photosynthesis and yield by reducing water use and delaying drought stress via stomatal regulation (Ghannoum *et al.*, 2000). Thus climate change impacts crops at various levels and influences the yield and quality of produce. For instance, elevated CO₂ may reduce the protein concentration (Ainsworth and Long, 2005), particularly in nitrogen limiting environments. Similarly, contents of anthocyanin, carotene, starch, oil, flavonoids, lycopene, *etc.* are affected in various crops (Ainsworth and Long, 2005).

5. Observed Impacts on Agriculture: Some Examples

Indian agriculture is often called as a 'gamble of monsoon' and is prone to climatic risks. The climate related aberrations have been significantly affecting the crop productivity in India. Several examples on climatic-stress related yield loss exist for annual crops and are relatively well documented. Unfavorable monsoon has been affecting the productivity of Kharif season crops. The terminal heat stress and early heat stress is lowering wheat yields while extreme weather events are affecting almost all crops. For instance, heavy rainfall in Madhya Pradesh during pod maturation affected the soybean yields during 2013 monsoon season. In 2014 and 2015, hailstorms in Maharashtra affected many horticultural crops. However, only a few examples are documented for perennial crops. For instance, unseasonal rainfall in March 2008 affected the quality and quantity of cashew yield, which can

be taken as an example of extreme weather event. On the other hand, consecutive droughts during 1998-2002 in Tamil Nadu and 2006-2007 in Karnataka have affected the coconut and arecanut yields, respectively, which can be an example of inter-annual extreme weather conditions (Naresh Kumar, 2011). Shift in apple cultivation from 1250 mamsl to 2500 mamsl to in Himachal Pradesh is partly attributed to the non- fulfillment of chilling requirement for apple due to rise in temperature (Bhagat *et al.*, 2009). This is one of the classical examples of mean change in climatic condition of a region.

6. Projected Impacts on Agriculture and Adaptation Gains

Globally, climate change is projected to affect the productivity of wheat, maize and soybean (Esterling *et al.*, 2007; Asseng *et al.*, 2015, IPCC 2014). Analysis at Environmental Modelling lab, Indian Agricultural Research Institute indicated that, on all India basis, the impacts of climate change on yields in 2030s range from -2.5 to -12 per cent for crops such as rice, wheat, maize, sorghum and mustard (Naresh Kumar *et al.*, 2011, 2012, 2013, 2014a and b). On the other hand, yields of some crops such as soybean, potato (in north- west India) and coconut (in west coast and in north east India) are projected to gain due to climate change (Naresh Kumar *et al.*, 2012; Naresh Kumar and Aggarwal, 2013). However, these impacts have spatial variation. For instance, positive impacts are projected for potato yields in north-west India while potato in central India may be affected. Adaptation can enhance the rice (+20 per cent), wheat (+11 per cent), maize (+21 per cent), mustard (+25 per cent), sorghum (+8 per cent), soybean (+12 per cent), potato (+8 per cent, all India) and coconut (+33 per cent all India) yield in future as indicated by the simulation analysis (Naresh Kumar *et al.*, 2011, 2012, 2013, 2014a and b; 2015; Naresh Kumar and Aggarwal, 2013).

7. Effects of Climate Change on Coconut

In India coconut is mainly grown in Kerala, Karnataka, Tamil Nadu, Andhra Pradesh, Maharashtra, West Bengal and Assam (Table 2.1). These plantations provide sustenance to the millions of the farmers across these states. Kerala and North-eastern states are generally characterized by coconut based home-stead gardens, forming the backbone for the livelihood security of millions. Thus it is important to quantify the impact of climate change on coconut plantations and formulate the suitable adaptation strategies. Even though coconut is grown in over 200 districts in India, the major producing area is confined to just about 20 districts (Figure 9.2), which contribute almost 70 per cent to national production. Eleven out of 14 districts of Kerala together contribute ~ 22 per cent to the national production. Contribution from Tamil Nadu (~31 per cent), Karnataka (~23 per cent) and Andhra Pradesh (~8 per cent) mainly comes from 10 districts. Thus, majority of coconut production is confined to a very small area making it's production more dependent on climatic factors.

It is important to understand the impact of climate change on plantation crops which, being perennial in nature, face climate change and variability even during a single generation or in a standing plantation. For example a seedling of coconut, with all likelihood, will face the increased CO₂ concentrations, temperatures, changed

Table 2.1: Relative Contribution of Coconut Area, Production, Productivity by different States in India

States/Union Territories	Area ('000 ha)	Contribution to Total (per cent) Area	Production (Million nuts)	Contribution to Total (per cent) Production	Productivity (Nuts/ha/year)
Andaman and Nicobar	21.9	1.02	129.97	0.60	5935
Andhra Pradesh	121.92	5.70	1828.46	8.44	14997
Assam	20.23	0.95	136.61	0.63	6753
Bihar	15.25	0.71	141.42	0.65	9273
Chhattisgarh	1.52	0.07	22.1	0.10	14539
Goa	25.75	1.20	128.13	0.59	4976
Gujarat	31.63	1.48	295.03	1.36	9328
Karnataka	517.29	24.17	5041.15	23.27	9745
Kerala	797.21	37.24	5968.01	27.55	7486
Lakshadweep	2.57	0.12	70.91	0.33	27591
Maharashtra	28.08	1.31	187.47	0.87	6676
Mizoram	0.03	0.00	0.12	0.00	4000
Nagaland	1.45	0.07	16.32	0.08	11255
Odisha	50.78	2.37	324.93	1.50	6399
Puducherry	1.96	0.09	34.09	0.16	17393
Tamil Nadu	465.11	21.73	6917.25	31.93	14872
Telangana	1.61	0.08	24.09	0.11	14963
Tripura	6.91	0.32	28.3	0.13	4096
West Bengal	29.3	1.37	370.83	1.71	12656
All India	2140.5		21665.19		10122

Source: Coconut Development Board, Kochi.

rainfall amount and pattern, etc. in next 60 years of its economic yield producing life span. Keeping in view the fact that coconut plantations are grown in ecologically sensitive regions such as coastal regions, the research on understanding the impacts of climatic stresses and climatic change on coconut was initiated at Central Plantation Crops Research Institute, Kasaragod, India during 2002. World over, this has been the first comprehensive climate change study on coconut.

7.1. Approaches for Climate Change Studies

Quantification of impact of major climate change parameters such as increased temperature and CO₂, and change in rainfall on crops is done using three approaches, viz., field or controlled environment experiments, meta-analysis and simulation models. In field experimentations, quantifications are done by growing crops in Open Top Chamber (OTC) or in Free Atmospheric Carbon dioxide Enrichment

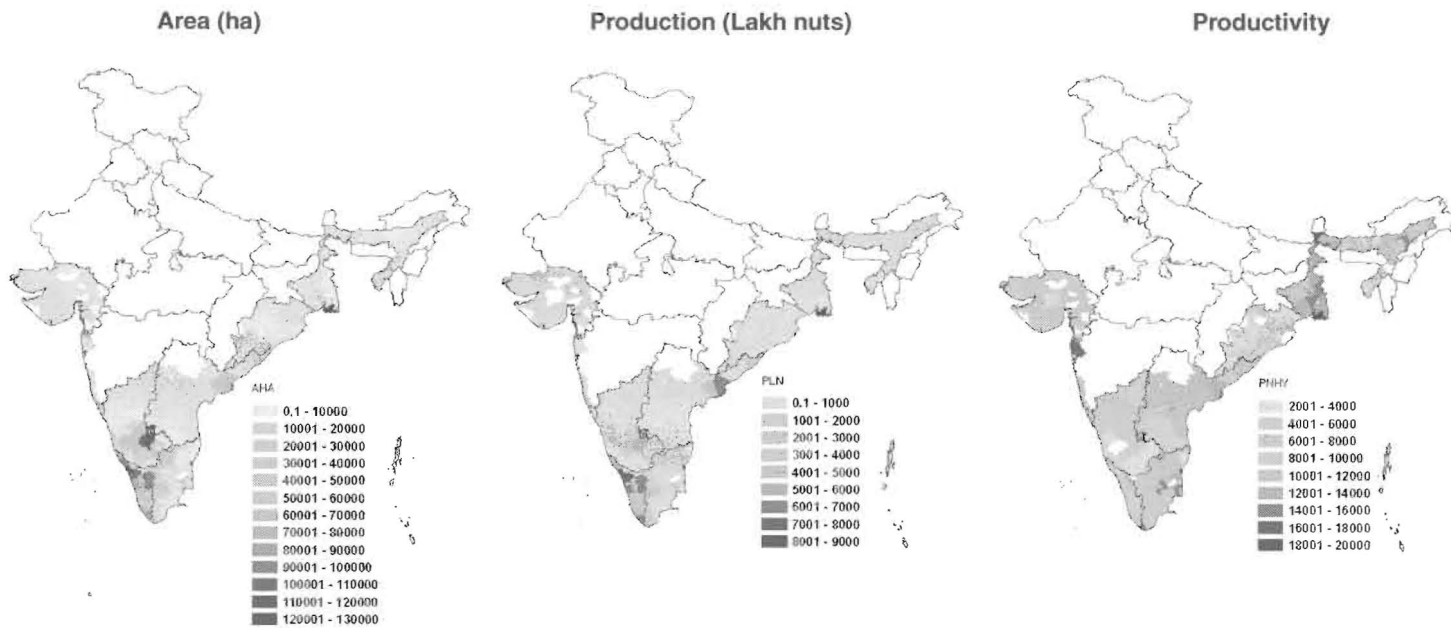


Figure 2.2: Spatial variation in area production and productivity of coconut in India

(FACE) rings, in Free Atmospheric Temperature Elevation (FATE) rings and in T-FACE facilities (where both temperature and CO₂ are modified). These studies provide vital information on crop response to elevated CO₂ or temperature or to both, in spite of being costly and time taking procedure. However, the information generated cannot be generalized for regional/state or national level.

Meta-analysis and analysis of past data indicates the climate related impacts but it is difficult to effectively desegregate confounding effects of technological and other interventions even by different de-trending methods. Another major limitation is that CO₂ effects cannot be delineated and thus derived future projections are not reliable. The other approach is to use well validated simulation models. Simulation models are strong tools which provide opportunity to use various climate change scenarios in combination with different management parameters for analyzing the regional impacts, adaptation and vulnerability. Apart from these, well developed crop simulation models provide opportunity to assess the impacts of climatic variability on crop growth. Such studies provide the guidelines for 1) relative advantage of adaptation strategies to be followed for minimizing the climate change impacts 2) best possible adaptation strategy 3) technology development needs 4) research gaps 5) regional spatial and temporal variation for yield gap 6) regional policy direction and so on. Further, crop simulation models coupled with remote sensing and geographical information systems (RS-GIS) prove to be strong tools for not only impact, adaptation and vulnerability assessments, but also for land use change and land use plan as well as for yield forecasting, crop monitoring and management. Use of more than one strategy and coupling of strategies provide more robust information and assessments.

7.2. Impact of Climate Change on Coconut

In assessing the impact of climate change on coconut and for deriving the adaptation strategies, a five-pronged strategy *viz.*, 1) quantification of response of coconut seedlings to elevated CO₂ (550 and 700 ppm) and temperature (+2°C over control OTC) in Open Top Chamber system, 2) field experiments, multi-location experiments, 3) lab experiments, 4) surveys and 5) simulation analysis using InfoCrop-COCONUT model was used (Naresh Kumar et al, 2007a). With the development of a simulation model for coconut (Naresh Kumar *et al.*, 2008), it became possible to simulate effects of various climate change scenarios in combination with different management parameters for analyzing the regional impacts. Coconut model has immense potential for plantation management decisions in India and in other parts of the world. At CPCRI, Kasaragod, an Open-Top Chamber facility is used for quantifying the impacts of elevated CO₂ and temperature on coconut and areca nut seedlings and cocoa grafts (Naresh Kumar et al, 2007a).

7.2.1. Results from the Open Top Experiments

The experiments conducted at Central Plantation Crops Research Institute, India using the Open Top Chambers (Figure 2.3) from 2006 provided the first estimates of the response of coconut seedlings to elevated CO₂ and temperature (Naresh Kumar, 2007-2010; 2011; Naresh Kumar *et al.*, 2011, Muralikrishna *et al.*, 2009; 2013, Muralikrishna 2012, Sunoj, 2012; Sunoj *et al.*, 2009, 2013, 2014, 2015; Hebbar et



Figure 2.3: Open Top Chamber Facility for Studying the Effect of Elevated CO₂ and Temperature at CPCRI, Kasaragod, India.

al. 2013). Seedlings of coconut (2 hybrids and 3 cultivars), arecanut (5 cultivars) and cocoa (3 hybrids and 4 cultivars) were grown in Open Top Chamber facility with SCADA controlled pumping and monitoring of CO₂ to set level of 550 and 700 ppm and hot air for elevated temperature (+2°C).

After exposure of seedlings for three years, results indicated that in general, elevated [CO₂] at 550 and 700 $\mu\text{mol mol}^{-1}$ benefited the growth and development of coconut seedlings (Figure 2.4) as they assimilated more carbon dioxide, due to higher photosynthetic rates and larger leaf area, resulting in significant increase in shoot and root biomass (Table 2.2). The leaf water balance was maintained by thicker cuticle, by reduced stomatal density and by regulation of stomatal conductance in both elevated [CO₂] and temperature. The growth of seedlings, grown in open top chamber with elevated temperature of 3°C above 31°C (the annual mean maximum



Figure 2.4: Response of Coconut Seedling to Elevated CO₂;
(a) Control (b) 550 ppm CO₂ and (c) 700 ppm CO₂.

temperature of experimental site, was significantly reduced (Figure 2.5) consequent to the reductions of leaf area (>50 per cent), chlorophyll content (>40 per cent) net photosynthesis as compared to control. However, there was higher deposition of epicuticular wax on the leaves.

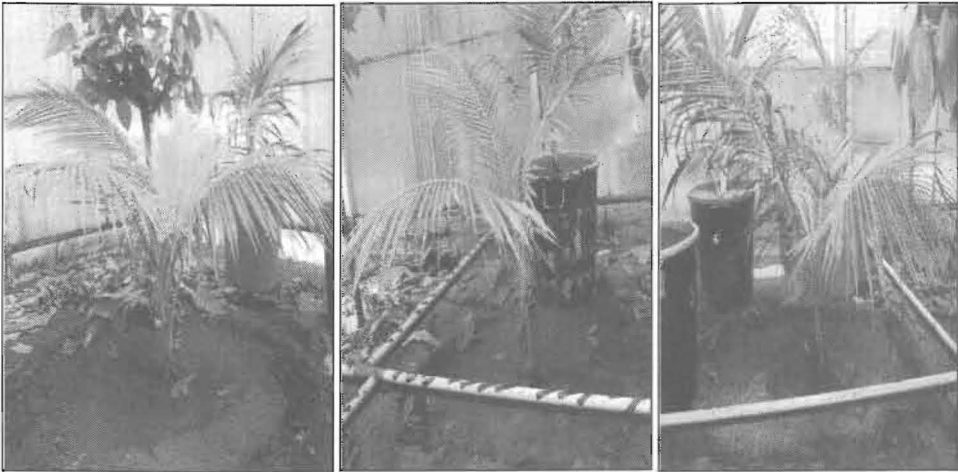


Figure 2.5: Response of Coconut Seedling to High Temperature;
(a) Control (b) Ambient +3°C (c) 550 ppm CO₂ + Ambient +3°C.

In general, plants are more sensitive to high temperature during reproductive phase than vegetative stage. Pollen grains are highly sensitive to high temperature. Coconut cultivars CGD, MGD, MYD, MOD and WCT indicated a wide variability in optimum temperature requirement for pollen germination and tube length growth. At 20°C WCT had a germination of 90 per cent and reduced to 42 per cent at 40°C (Figure 2.6). Across all the temperatures, pollen germination was highest in WCT followed by MGD and was the least in MYD (Figure 2.7) (Hebbar and Chaturvedi, 2015). Cultivar differences for heat tolerance exist in some crops such as rice, cowpea, and peanut, but knowledge about the effects of extreme high temperatures is very limited in coconut because diverse germplasm has not been extensively screened.

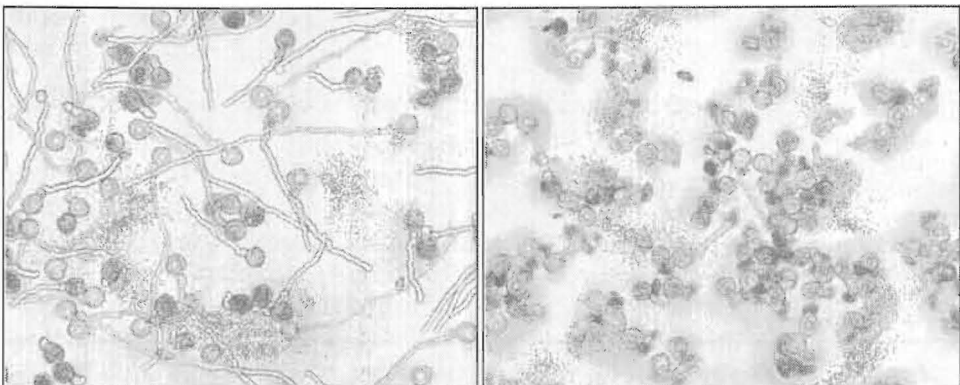


Figure 2.6: Pollen Germination of WCT at 25 (Left) and 40°C (Right).

Table 2.2: Influence of Elevated Temperature and CO₂ on Anatomical, Physiological and Biochemical Parameters of Coconut Arecanut and Cocoa Seedlings (Source: Naresh Kumar 2007a)

Parameter	% change from chamber control		
	Temp. (2+°C)	CO ₂ (550 ppm)	CO ₂ (700 ppm)
Coconut			
Specific leaf weight	3.6	28.5	2.9
Net photosynthetic rate	-15.8	21.0	85.6
Stomatal conductance	-20.7	-53.3	-25.9
WUE	1.6	124.7	81.2
Leaf water potential	-54.4	11.6	2.3
Chlorophyll a/b ratio	1.9	7.7	1.4
Stomata density	-5.9	-10.7	-14.0
Lower cuticular thickness	16.7	23.5	26.0
Phenols concentration in leaf	-28.5	-2.1	-2.1
Proline in leaf tissue	5.4	121.7	97.1
Total soluble sugars in leaf tissue	-29.7	204.	41.4
Reducing sugars in leaf tissue	-44.7	29.9	58.0
Amino acids in leaf tissue	5.3	26.4	109.6
Starch in leaf tissue	-10.4	428.2	366.1
SOD activity	67.4	17.4	11.3
PPO activity	-67.7	-80.6	-77.4
Nitrogen in shoot tissue	-15.0	6.0	24.6
Nitrogen in root tissue	-7.2	31.9	13.0
CN ratio shoot	17.4	-6.5	-20.1
CN ratio root	8.2	-24.5	-11.0
Arecanut			
Total dry matter	-8.6	8.4	22.1
SLW	-33.6	-44.0	-38.1
Net photosynthetic rate	13.4	15.0	109.1
Leaf water potential	-10.6	24.6	10.0
Chl a/b ratio	27.8	17.6	10.2
Leaf thickness	-0.5	10.9	12.9
Amino acids in leaf tissue	-24.8	95.6	12.9
Total soluble sugars in leaf tissue	49.3	17.6	7.7
Starch in leaf tissue	54.8	154.5	86.3
Phenols in leaf tissue	25.4	20.2	0.4
Nitrogen in shoot tissue	4.4	6.8	7.3
Cocoa			
Root/shoot ratio	2.5	-12.0	-11.5
Total dry matter	-31.5	10.4	33.5
Number of roots	-48.3	-21.0	-15.9
Net photosynthetic rate	15.7	73.9	97.6
WUE	-3.8	20.7	60.4
Leaf water potential	-6.2	12.5	26.6
Chl a/b ratio	3.9	2.8	10.6
Total chlorophyll	25.1	16.1	35.7
SLW	-2.2	7.5	4.3
Leaf let thickness	-3.5	10.7	12.9
Total soluble sugars in leaf tissue	-3.7	-13.8	-13.6
Starch in leaf tissue	37.3	154.5	78.4
Phenols in leaf tissue	-4.0	-11.2	-8.7

The biochemical analysis indicated that elevated [CO₂] increased the concentrations of leaf biochemicals such as soluble sugars, reducing sugars, free

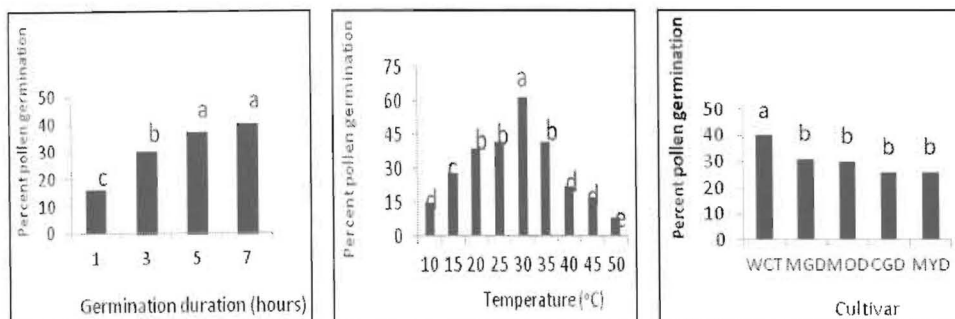


Figure 2.7: Effect of Temperature on Pollen Germination, (a) Percentage of pollen germination in WCT at 20°C, (b) Percentage of pollen germination at different temperatures in WCT for the period of 5 Hr, (c) Percentage of pollen germination of varieties (CGD, MGD, MYD, MOD and WCT) at different temperatures.

amino acids, starch and proline. The specific activities of superoxide peroxidase and catalase also increased. On the other hand, elevated $[\text{CO}_2]$ reduced the concentration of total phenols, polyphenol oxidase activity and shoot and root CN ratio. Elevated $[\text{CO}_2]$ also increased the activities of rhizosphere soil amylase, cellulase due to reduction in soil pH. Elevated temperature significantly increased concentration of leaf total free amino acids, proline and heat stable protein fraction. Apart from these the CN ratio in shoots and roots increased as also the activities of superoxide dismutase, catalase and soil invertase and soil cellulase. On the other hand, elevated temperature significantly reduced concentrations of leaf total soluble sugars, reducing sugars, total phenols, starch and reduced the activities of poly phenol oxidase and peroxidase. Coconut plantations may become more prone to diseases and pests due to reduction on the concentration of phenols in future climates.

Availability of soil nutrients in elevated $[\text{CO}_2]$ and temperature condition, in general shown a reduction, except that of Na, K and Mg in elevated CO_2 . This is an indicator of a possible higher requirement of fertilizer application in future scenarios. Results further indicated that in spite of variations in leaf and soil biochemical concentrations, coconut seedlings have capacity to adapt to future climate through changes in biochemical mechanisms that make some cultivars more suitable than others.

7.2.2. Impact of Elevated Temperatures on Quality of Coconut Copra and Oil

The copra yield/nut, oil percentage and fatty acid profiles of various cultivars grown at different agro-climatic zones was analyzed for their relationship with the weather during nut growth periods for the nuts harvested during January, April, July and October months (Naresh Kumar, 2005). The analysis indicated impact of Tmax, Tmin, Rainfall, RH on the copra yield/nut, oil per cent and fatty acid composition in coconut oil. The saturated to unsaturated fatty acid ratio increased with rise in minimum temperature, while it slightly decreased with rise in maximum temperature (Figure 2.8). Copra weight/nut decreased while oil percentage slightly increased with rise in maximum temperatures.

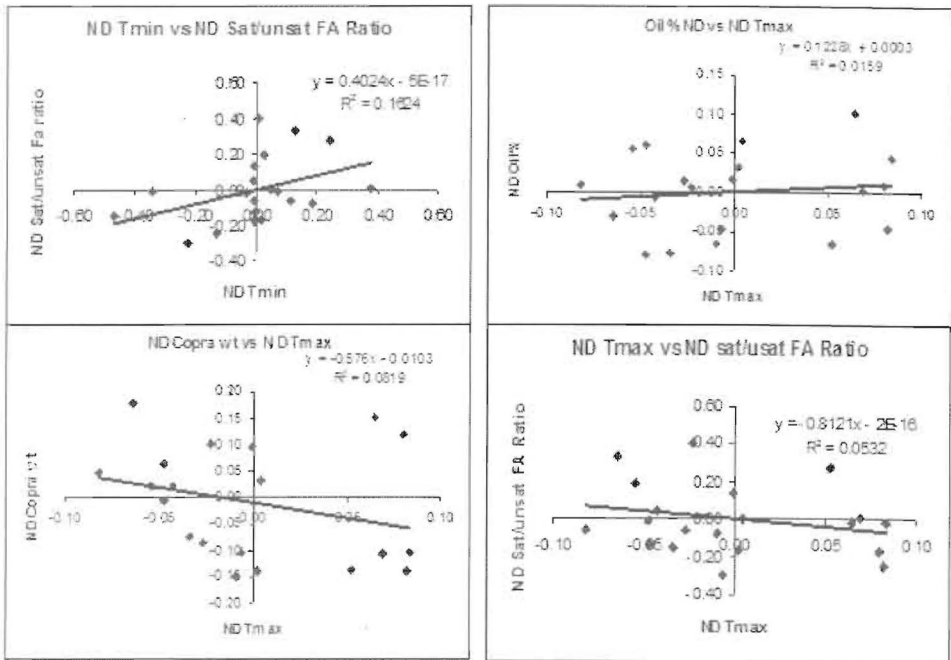


Figure 2.8: Normalized Deviation Analysis of Coconut Quality Parameters in Relation to Temperature Deviations.

7.2.3. Observed Impacts of Weather Extremes on Coconut Plantations

Examples

A study on the impact of climatic risk events like cyclones and droughts on coconut indicated that consecutive drought years in Coimbatore district of Tamil Nadu and Tumkur district of Karnataka in India caused not only severe reduction in yield but also left about 2 lakhs palms dead in both the districts (Naresh Kumar, 2011). More than 6 lakh palms were severely affected. Consecutive droughts in Coimbatore district reduced the coconut production by about three lakh nuts/year for four years. Productivity loss was to the tune of about 3500 nuts/ha/year (Naresh Kumar *et al.*, 2010, Naresh Kumar 2011). Length and frequency of dry spell has negative impact of coconut yields in different agroclimatic zones (Naresh Kumar *et al.*, 2007, Naresh Kumar 2011).

In Godavari districts of Andhra Pradesh, cyclone in 1995 badly affected the coconut yields. The yields drastically reduced in 1995-96 and then it took four to five years for the recovery of affected gardens. Reduction in coconut yields was to the tune of 3350 lakh nuts/year for 6 years. The loss in East Godavari district was to the tune of about 2200 lakh nuts/year for six years. The productivity was reduced by 6200 nuts/ha/year in East Godavari district and by ~4100 nuts/ha/year in Andhra Pradesh. During 2003-04 only the production levels could reach pre-cyclone period thus severely affecting the production for six years (Naresh

Kumar *et al.*, 2008, Naresh Kumar 2011). The impact of super cyclone in Odisha during 1999 caused severe loss to coconut plantations resulting in perennial loss of income to the farmer.

7.2.4. Climate Change Projections for Coconut Growing Regions in the World and in India

Climate change becomes particularly important for coconut plantations on three counts, in addition to those mentioned earlier. 1) Of the 12.9 Mha area under coconut plantations in the world, majority of area (~70 per cent) falls in the coastal zone, 2) Among the 90 countries that grow coconut, majority are islands. 3) Majority of the plantations are rainfed. As all regions of the world, coconut growing regions also are projected to face climate change. The climate models project (IPCC, 2014) the increase in temperature of 1.8-5.1°C in across these regions. The precipitation is projected to change -15 to 25 per cent in these regions. In addition, increase in the heavy rainfall events, a decline in winter rainfall, sea level rise, frequent intense tropical cyclones and change in *El Nino* are projected. All these potentially damage the coastal ecosystems and affect coastal agriculture including coconut plantations.

In India, during 1960-1990 period, the annual mean maximum temperatures ranged from 25.3 to 36°C and annual mean minimum temperatures ranged from 15.6 to 26°C in the coconut growing areas. Annual rainfall ranged from 600 to 4500 mm in these areas. Currently, east-coast is warmer and receives less rainfall as compared to the west-coast areas. Coconut growing areas in eastern and north-eastern region are characterized by hot summers and cold winters. North-east region also receives high rainfall. Climate change is projected to increase the temperatures by 1.26-2.4°C and change in annual rain fall in the range of -13 to 20 per cent by 2030 in the coconut growing areas. By 2080 temperatures are projected to rise by 2.95 to 4.9°C and annual rain fall is projected to change in the range of -15 to 30 per cent in these areas. However, these changes will have spatial and temporal variations.

7.2.5. Projected Impacts of Climate Change on Coconut Plantations

A review of literature indicates that mainly two methods are applied for analyzing the climate change impacts on coconut productivity. In the first approach, using the statistical models, it was reported that changes in monsoon rainfall pattern and increase in maximum air temperature are two key factors on the variability of coconut production in the principal coconut growing regions of Sri Lanka (Peiris *et al.*, 2006). They indicated that the projected coconut production after 2040 in all climate scenarios, when other external factors are non-limiting, will not be sufficient to cater the local consumption for the increased population.

The second approach is to use simulation models. Development of InfoCrop-COCONUT model (Naresh Kumar *et al.*, 2008), which can simulate the growth, development and yield of coconut taking into account of soil characteristics, weather, management and varietal characteristics, enabled researchers to use the later approach for coconut (Naresh Kumar and Aggarwal, 2009, 2013) InfoCrop-COCONUT is being released as CocoSim.

The simulation analysis on all India basis projected an increase in coconut productivity up to 4 per cent during 2020, up to 10 per cent in 2050 and up to 20

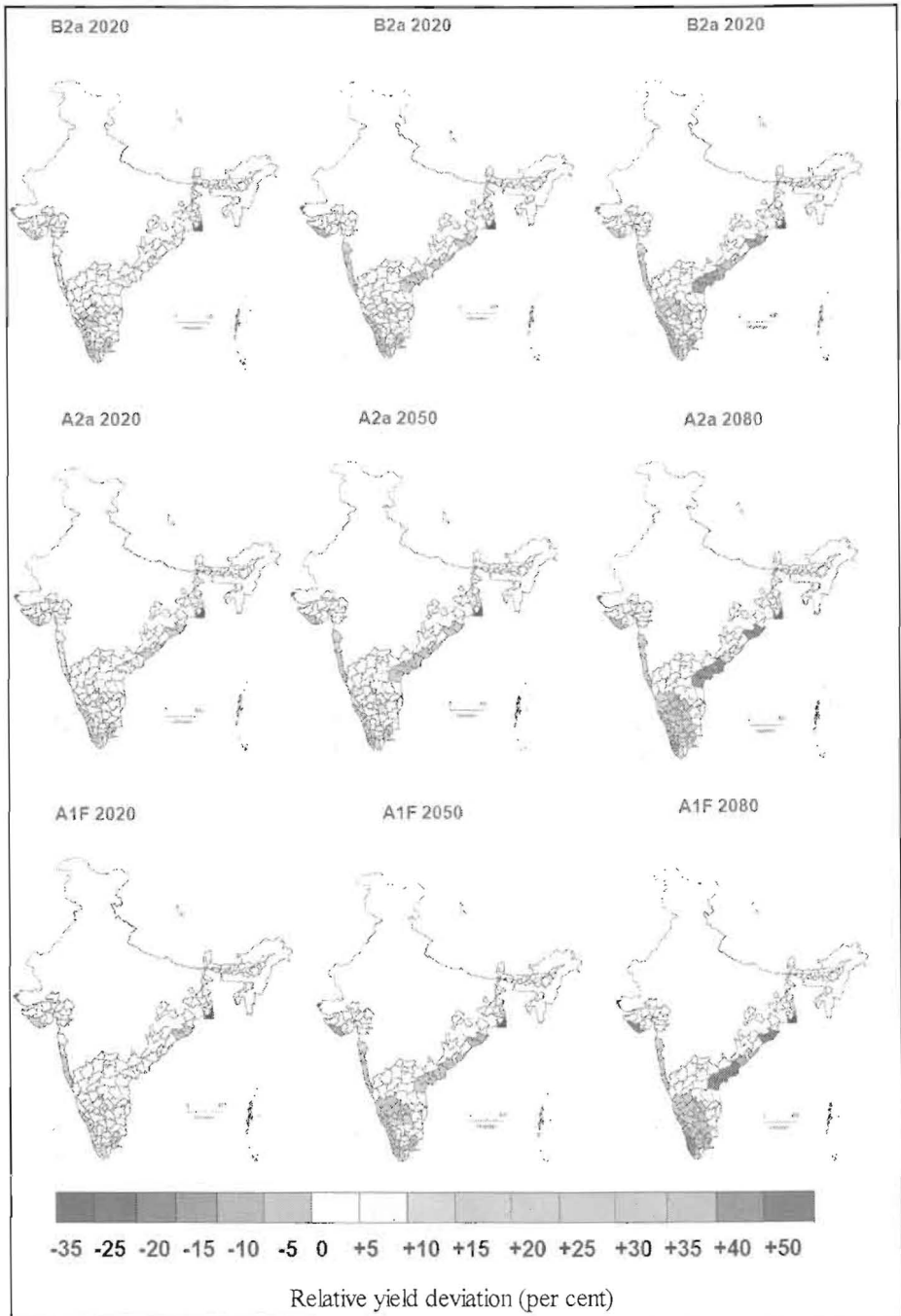


Figure 2.9: Impact of Climate Change on Coconut Productivity in 2020, 2050 and 2080 Climate Scenarios Based on HadCM3 Scenarios. The yield change is relative to mean productivity of coconut for five years (2000-2005) period (Source: Naresh Kumar, 2010).

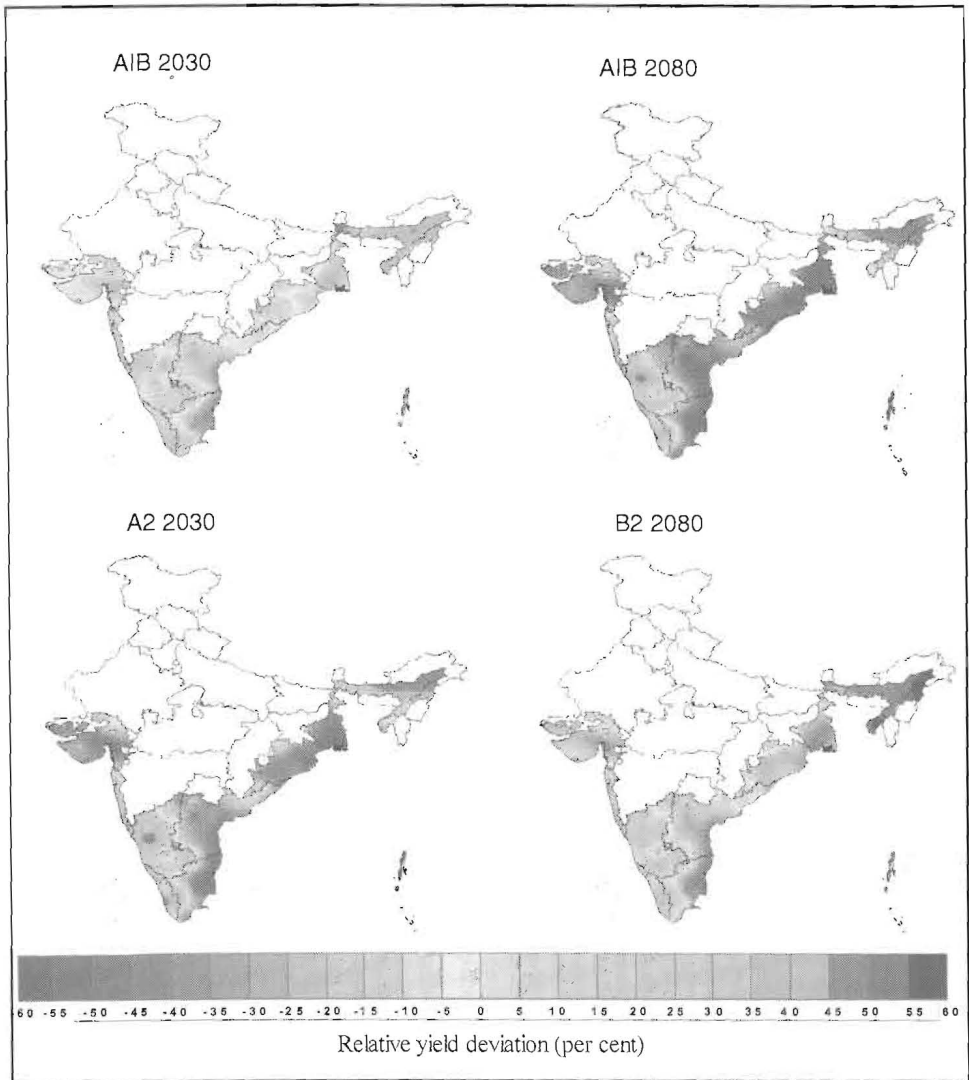


Figure 2.10: Spatial Variation in Impact of Climate Change on Coconut Productivity in India Based on High Resolution PRECIS A1B 2030 and 2080; A2-2080 and B2-2080 scenarios. The yield change is relative to mean productivity of coconut for five years (2000-2005) period (Source: Naresh Kumar and Aggarwal, 2013).

per cent in 2080 over current yields in HadCM3 A2a, B2a and A1F and PRECIS A1b scenarios (Figures 2.9 and 2.10). In west coast, yields are projected to increase by up to 10 per cent in 2020, up to 16 per cent in 2050 and up to 39 per cent by 2080 whereas in east coast yields are projected to decline by up to 2 per cent in 2020, 8 per cent in 2050 and 31 per cent in 2080 scenario over current yields (Naresh Kumar and Aggarwal, 2009).

Table 2.3: Impact of Climate Change in Major Coconut Growing States different Scenarios

State	A1b2030	B1b2080	A2 2080	B2 2080
	<i>(per cent change from current production)</i>			
Andaman and Nicobar	7.4	-10.3	4.9	15.0
Andhra Pradesh	-1.4	-31.4	-21.2	-3.4
Assam	59.1	>60.0	>60.0	>60.0
Goa	35.6	42.5	52.6	46.7
Gujarat	-9.0	-38.6	-38.0	-19.2
Karnataka	5.3	-8.8	-9.5	-11.2
Kerala	6.5	18.5	21.2	14.0
Lakshadweep	6.5	33.5	34.5	16.5
Maharashtra	15.7	25.6	30.5	26.3
Nagaland	>60.0	>60.0	>60.0	>60.0
Odisha	-6.5	-48.2	-40.7	-16.9
Puducherry	-25.7	-45.2	-41.0	-30.8
Tamil Nadu	-1.6	-10.3	-5.3	-2.8
Tripura	54.6	>60.0	>60.0	>60.0
West Bengal	2.9	-39.6	-24.2	-3.9
All India	4.3	1.9	6.8	5.7

Source: Naresh Kumar, 2010; Naresh Kumar and Aggarwal, 2013.

Subsequent fine resolution analysis projected increase in coconut productivity in western coastal region, Kerala, parts of Tamil Nadu, Karnataka and Maharashtra (provided current level of water and management is made available in future climates as well) and also in North-Eastern states, islands of Andaman and Nicobar and Lakshadweep and yield decrease for Andhra Pradesh, Odisha, West Bengal, Gujarat and parts of Karnataka and Tamil Nadu due to climate change. On all India basis, coconut productivity is projected to increase by 4.3 per cent in A1B 2030, 1.9 per cent in A1B 2080, 6.8 per cent in A2 2080 and 5.7 per cent in B2 2080 scenarios of PRECIS over mean productivity of 2000–2005 period.

7.3. Adaptation Strategies to Climate Challenges on Coconut Plantations

In plantation crops, management of crop becomes very important during adverse conditions in order to sustain the productivity. Since a standing plantation crop will face the climate change and variability effects during their life period due to perennial nature, the multi-pronged strategy may be adapted to reduce the adverse impacts of climate change and also to maximize the positive effects of climate change (Figure 2.11).

Simulation analysis indicated that agronomic adaptations like soil moisture conservation, summer irrigation, drip irrigation, and fertilizer application cannot

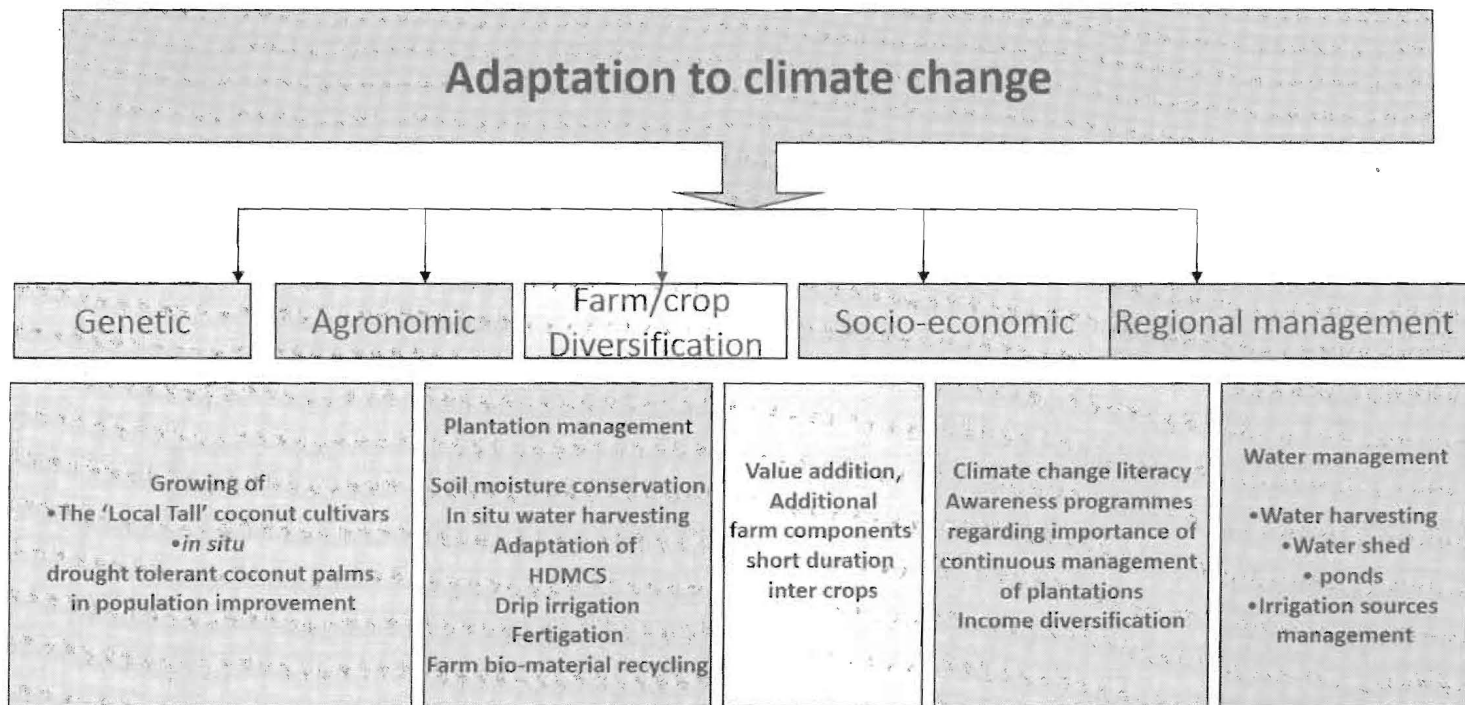


Figure 2.11: Framework for Adaptation of Plantation Crops to Climate Change.

only can minimize losses in majority of coconut growing regions, but also improve productivity substantially. Further, genetic adaptation measures like growing improved local Tall cultivars and hybrids under improved crop management is needed for long-term adaptation of plantation to climate change, particularly in regions that are projected to be negatively impacted by climate change (Figures 2.12 and 2.13). Such strategy can increase the productivity by about 33 per cent in 2030, and by 25–32 per cent in 2080 climate scenarios in India (Naresh Kumar and Aggarwal, 2013). In fact, productivity can be improved by 20 per cent to almost double if all plantations in India are provided with above mentioned management even in current climates (Naresh Kumar and Aggarwal, 2013). In places where positive impacts are projected, current poor management may become a limiting factor in reaping the benefits of CO₂ fertilization, while in negatively affected regions adaptation strategies can reduce the impacts. Thus, intensive genetic and agronomic adaptation to climate change can substantially benefit the coconut production in India (Naresh Kumar and Aggarwal, 2013). This analysis indicates that in changing climates, coconut productivity i) increase in some regions ii) some regions need adaptation to offset the yield loss iii) other regions remain vulnerable despite adaptation (Figure 2.10; Table 2.3). This information becomes extremely useful to initiate focused research activities for developing the integrated and novel adaptation strategies so that the i) beneficial effects of climate change can be harnessed and ii) projected vulnerable regions sustain yields in future climates as well. Similar analysis is needed for all coconut growing areas of the world as well as for other plantation crops so that effective adaptation strategies can be developed and implemented. Moreover, such analysis also provides a direction to researchers for developing the crop improvement and management strategies.

Data indicate substantial gains obtainable by adapting to climate change. In Kerala, providing more fertilizers along with summer time irrigation coupled with soil moisture conservation can further improve the positive gains due to climate

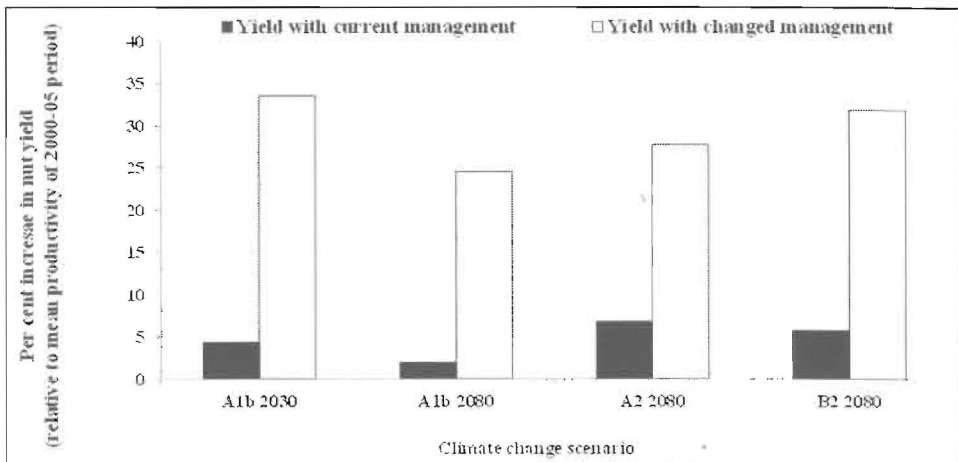


Figure 2.12: Change in all India Average Coconut Yield Due to Climate Change with and Without Adaptation (Source: Naresh Kumar and Aggarwal, 2013).

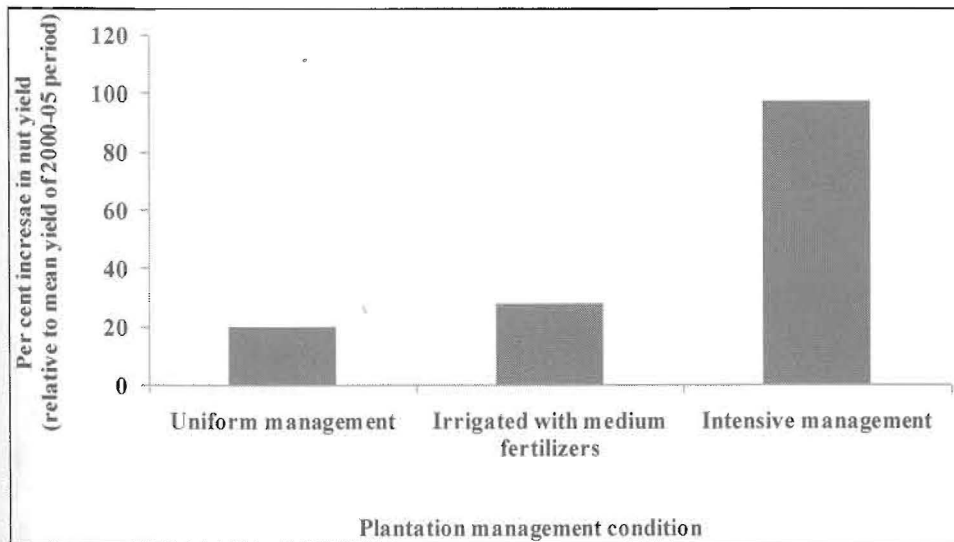


Figure 2.13: Gains in Nut Yield due to Adoption of Improved Management in Current Climates in India. The yield change is relative to mean productivity of coconut for five years (2000-2005) period. In irrigated with medium fertilizers, all farmers in India are assumed to provide assured irrigation and supply at least 2/3rd of the location specific recommended dose of fertilizers. (Source: Naresh Kumar and Aggarwal, 2013).

change by about 40 per cent in different scenarios. In Karnataka, West Bengal, Gujarat, Maharashtra and Odisha assured irrigation and providing more fertilizers not only can off-set the negative impacts but can result in higher yields. Adaptation gains in these states ranged from 2-47 per cent in different scenarios. In order to offset the negative impacts of climate change in Andhra Pradesh and Tamil Nadu, intensive management of plantations is needed. This includes planting of improved and tolerant varieties as well. In North-Eastern states, providing summer irrigation and even low dose of fertilizers can further improve the positive impacts of climate change. Similarly, coconut plantations in islands, if managed scientifically –by proper spacing or by canopy management- and by providing summer irrigation and even low dose of fertilizers, yield can be improved by 70 per cent in future climates (Naresh Kumar and Aggarwal, 2013).

Drought in current year not only affects the current year yield but also that of subsequent years. In coconut, the drought impact is worst in 3 and 4th year to follow (Rajagopal *et al.*, 1996; Naresh Kumar *et al.*, 2007b). Apart from this recovery will take 3-4 years thus causing a perennial loss in farm income. Thus, crop management becomes very important aspect. Multi-location trials on soil moisture conservation practices indicated very significant improvement in yield due to prolonged retention of soil moisture (Naresh Kumar *et al.*, 2006). The low-cost measures include basin mulching with husk/leaves/other farm biomass, burial of composted coir pith, hush burial, which acts as the moisture storage and retention mechanism in palm/plant basin (Naresh Kumar, 2004). This helps to reduce the amount and frequency of irrigation. Drip irrigation has proved to be very effective method of saving coconut

plantations in drought condition. Drip irrigation could save coconut plantations from consecutive drought impacts in Tamil Nadu during 1998-2002 period (Figure 2.14).



Figure 2.14: Effect of Drip Irrigation on Coconut Plantations during Consecutive Drought Years (1998-2002) in Pollachi Area of Tamil Nadu. Plantation in the left side is with drip irrigation.

Fertigation (Subramanian *et al.*, 2012) along with soil moisture conservation practices is one of the important water management strategies in climate change scenarios. By adapting this strategy and by providing higher nutrients, one can not only reduce the adverse impacts of climate change but also can maximize the positive impacts of climate change.

7.3.1. Genetic Improvement for Changing Climates

Genetic improvement is the most important aspect of sustaining coconut productivity, particularly in areas that are identified as vulnerable to climate change. For instance, in India east coast is projected to be vulnerable in spite of some adaptation measures. Cultivars having heat tolerance, pollen viability at high temperatures, pistillate flower formation and nut retention at high temperatures form some of the important parameters for selection criteria.

Growing of the 'Local Tall' coconut cultivars (*e.g.* WCT and LCT (for west coast), Tiptur Tall (for Karnataka), SakhiGopal Tall (for Odisha), ECT (for AP), in areas prone to water scarcity is one option. Utilization of identified *in situ* drought tolerant coconut palms (Figure 2.15) in population improvement programme is very important for making the crop more resilient to climate change conditions (Naresh Kumar 2004; Naresh Kumar *et al.*, 2006). High biomass production capability (Kasturi



Figure 2.15: *In situ* Drought Tolerant Palms Identified in Farmers' Fields in different Agro-climatic Zones and being Used in Population Improvement Studies (Source: Naresh Kumar, 2004).

Bai *et al.*, 1996) with high harvest index for oil, copra and nuts also should form the criteria for selection of the varieties in changing climates. Pest and disease defense should continue to be included in crop improvement efforts, as coconut palms may become vulnerable to pests and diseases in future.

7.3.2. Other Important Adaptation Options

- ☆ Crop diversification and high density multi-cropping system
- ☆ Water harvesting and recycling, water-cooperatives, drip irrigation and fertigation
- ☆ Increasing farmer awareness on farm natural resource management and input use efficiency
- ☆ Identification and adoption of low carbon technologies
- ☆ Area expansion in positive impact zones
- ☆ Value addition and income diversification
- ☆ Weather forewarning and weather-based agro-advisories
- ☆ Market-linkage and cooperative initiatives
- ☆ Income insurance safety nets such as crop insurance

Mitigation Potential of Coconut Plantations

The interaction between coconut and climate are two ways. While climate change influences coconut plantations, the climate itself is modified by the plantations. In climate change terminology, mitigation refers to i) reduction in GHG emission ii) capture of GHGs for long (typically over 30 years) period. Coconut plantations are very good candidates for mitigating the GHG emission 1) by acting as a source of biofuel and energy source, 2) carbon sequestration 3) micro-climate modification, and 4) air purification by O_2 release. Apart from these, coconut plantations and other plantation crops have multi-dimensional functions in the ecosystem and social system (Figure 2.16).

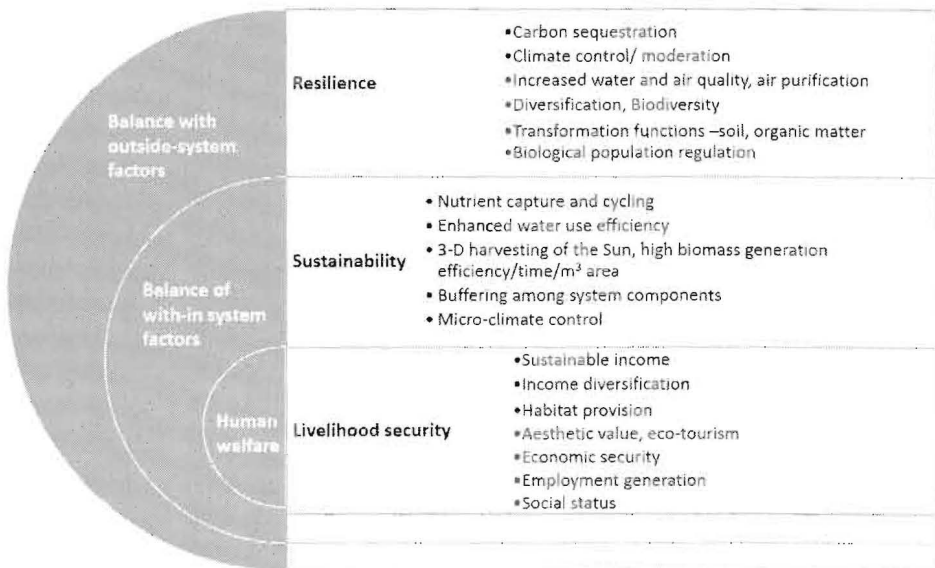


Figure 2.16: The Multi-dimensional Functions of Plantation Crops Systems (Naresh Kumar, 2015).

Coconut oil as biodiesel reported to reduce GHG emissions by about 60 per cent compared to the diesel (Pascual and Tan 2004). The net CO_2 emission from the carbon balance is equivalent to 77-104 g/MJ of diesel displaced by biodiesel (Tan *et al.*, 2004). Studies conducted in Vanuatu islands indicated possibilities of at least 9 per cent more profit, if covered under clean development mechanism over copra sales for coconut plantations (Roupsard *et al.*, 2004). The biodiesel conversion factor for coconut is taken at 130 L/Mg (FAO 2008, Johnston 2009). Utilization of coconut residues such as shells and husks for heat and power generation in the diesel production increases carbon savings in the range of 0.47-0.72 MgC/ha/yr (Vega, 2011).

Coconut plantations have immense potential to mitigate the GHG emissions by sequestering the carbon. The net primary production estimations of coconut monocrop in different agro-climatic zones of India indicated that carbon sequestration potential of coconut above ground biomass ranged from 8 Mg CO_2 /ha/year to 32 Mg CO_2 /ha/year depending on cultivar, agro-climatic zone, soil

type and management (Naresh Kumar, 2009). Annually sequestered carbon stocked in stem is in the range of 0.3 to 2.3 Mg CO₂/ha (Figure 2.17a). Annual carbon sequestration by coconut plantation is higher in red sandy loam soils and lowest in littoral sandy soils. The standing carbon stocks ranged from 15 Mg CO₂/ha to 60 Mg CO₂/ha in a 20 year old plantation (Figure 2.17b). Further, using coconut simulation model the carbon stocks in stem of coconut in its economic life span of 60 years is estimated to be around 120 Mg CO₂/ha (Naresh Kumar, 2009). It is estimated that coconut plantations in India have carbon sequestration potential of about 7.54 Mt C. y⁻¹, which is equivalent to about 27.6 Mt CO₂.y⁻¹ and approximately 0.013 per cent of the total GHG emissions from India in 2010 (Naresh Kumar, 2015). Total GHG emissions from India in 2010 were 2,136.8 million tonnes of CO₂eq (BUR, 2015).

Other studies also indicate that net ecosystem productivity of 20-year-old coconut plantation is about 8 Mg C/ha/year (~29 Mg CO₂/ha/year) at optimum fertilizers and irrigation (Roupsard *et al.*, 2006). Further, if amount of copra taken out of plantations is considered, a net sequestration is ranged from 3 to 5 Mg C/ha/year (~11-18.4 Mg CO₂/ha/year) (Roupsard *et al.*, 2008). Further analysis by Naresh Kumar, 2009 indicated that the carbon in nut yield, categorized as short to medium duration (~2 to 5 years) storage, is estimated to be around 1,350 Mg CO₂/ha during the entire economic life span of coconut. Around 50 per cent of this is husk, which can be recycled into the soil and around 22 per cent is shell, which stores carbon for longer duration. Remaining 28 per cent is removed as copra, which is rich in oil (~65 per cent). Besides, carbon storage in leaf and inflorescence, which again is for short to medium duration, is estimated to be around 1000 Mg CO₂/ha in entire span of coconut economic life of 60 years. Currently, many value added products are made out of husk, shell and leaves. If litter is recycled into the system for improving the soil organic carbon content, the improvement in soil organic carbon over a period of time will also qualify for the inclusion in carbon sequestration estimations.

Coconut plantations influence the microclimate of the system thus regulating the weather and climate of the place and region depending on the extent spread of the plantation. The estimated microclimate regulation by the coconut plantations are about 1°C at a regional scale (Naresh Kumar, 2015). Release of O₂ by coconut plantation is estimated to be around 36 Mg O₂/ha/year (Naresh Kumar, 2015). For full commercial exploitation, potential clean development mechanism projects in coconut should include biomass carbon sequestration, renewable energy generation, substitution and greenhouse gas mitigation. Though, currently coconut is not included as one of the species for carbon sequestration in carbon markets, the immense potential of coconut plantations in managing the climate change should be exploited for the benefit of all.

In the socio-economic front, the livelihood security of coconut farmers is greatly dependent on the remuneration from the coconut based farming and products. Geotextiles also provide a major scope for increased income in view of the increasing green-technology scenarios. Coconut plantations also serve as the green-buffer zones for adverse weather events. For instance during super-cyclone, which struck the cost of Odisha in India, many people survived for days by climbing on coconut palms and consuming the nuts. Coconut grooves are attractive tourist places. Therefore focused and concerted research efforts are required to quantify the ecosystem services and exploit immense potential of coconut plantations in the tropics.

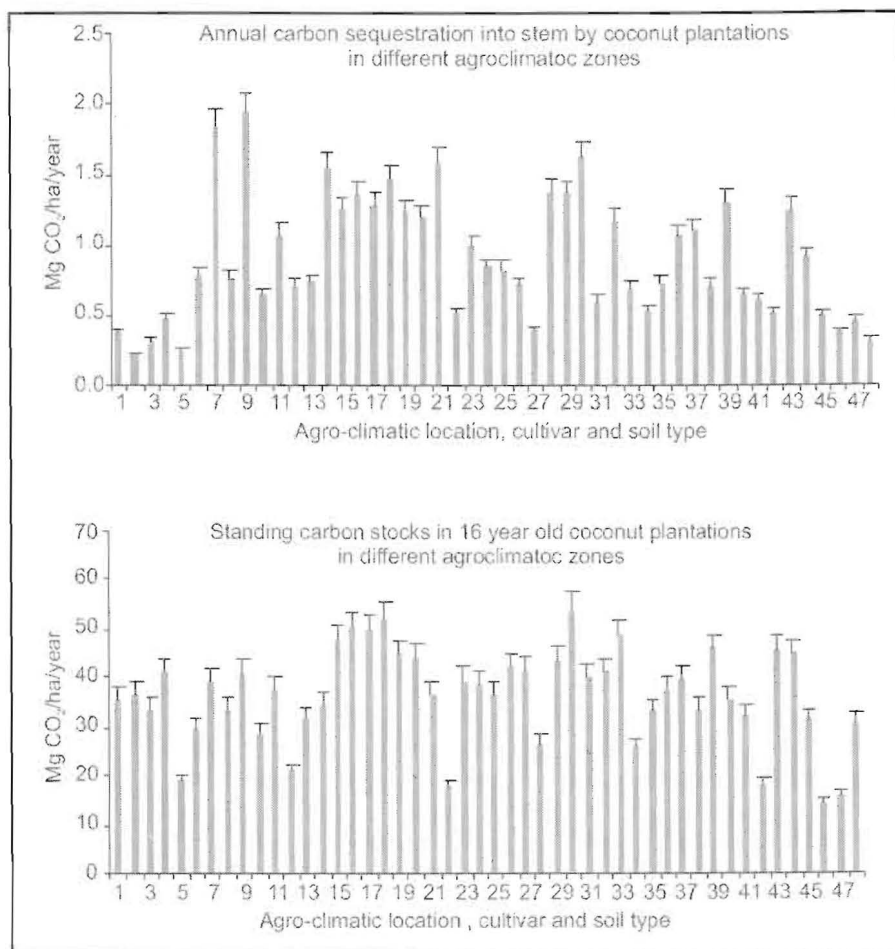


Figure 2.17: Annual Carbon Sequestration in Coconut Stem (a) and Carbon Stocks (b) in Coconut Plantations in different Agro-climatic Zones and Soil Types.

a: y-axis-I-irrigated; DI-drip irrigation; BCL- black clay loam soil; RSL-red sandy loam soil; RCL -red clayey loam soil; RL- red laterite soil; S-sandy soil; LS- coastal sandy soil; b, c and d -y axis – 1-5 Ambajipeta, clay loam, Irrigated (1-WCT, ECT, LCT, ECT × GBGD, GBGD); 6-14 Ratnagiri, drip irrigation, sandy loam (6-WCT, 7- ECT, 8-LCT, 9-ECT × GBGD, 10-GBGD, 11-Pratap, 12-COD, 13-WCT × COD, 14-COD × WCT); 15-28 Aliyarnagar, red sandy loam, irrigated (15-ECT × GBGD, 16-LCT × GBGD, 17-ECT × MYD, 18-Pratap, 19-GBGD × ECT, 20 – ECT, 21-LCT, 22-COD, 23- WCT, 24- COD × WCT, 25 -WCT × COD, 26- Tiptur Tall, 27- GBGD, 28-Arasampatty Tall); 29-38 Ariskeri, red clay and black clay, drip irrigated (29-LCT, 30- Arsikere Tall, 31-WCT (black clay), 32-WCT (red clay), 33-Tiptur Tall, 34-GBGD, 35-WCT × COD (black clay), 36-WCT × COD (red clay), 37-COD × WCT, 38- WCT × GBGD); 39-42 Kidu, red laterite, drip irrigated (39-ECT, 40-WCT, 41-LCT, 42-COD); 43-46 Veppankulum, sandy loam, irrigated (43- ECT, 44-WCT, 45-LCT, 46-COD); 47-48 Kasaragod, coastal sandy (47-WCT rainfed, 48- WCT-drip irrigated). Nems of coconut cultivars WCT- West coast Tall; ECT- East Coast Tall; LCT- Laccadive Ordinary Tall; GBGD-Gangabondam Dwarf; COD- Chowghat Orange Dwarf; MYD-Malayan Yellow Dwarf). (Source: Naresh Kumar, 2009).

Conclusions

Past adverse climate events such as droughts and cyclones severely affected the coconut yields. Coconut simulation model based projections indicate beneficial influence of climate change on coconut in western coast of India provided the current water sources are made available in future as well. On the other hand the plantations in irrigated areas of Tamil Nadu, Karnataka, Andhra Pradesh, Odisha and Gujarat are likely to be adversely affected causing loss of production. Quality of the produce is also likely to be affected with changes in nut composition and fatty acid profile of oil. Soil moisture conservation needs to be given paramount importance for crop production in the water limiting scenarios of future. Apart from this, development of 'green technologies', 'climate resilient varieties', 'climate proofing' by crop diversification, crop intensification, mixed farming need to be promoted. The carbon sequestration potential and ecosystem services of plantation crops need to be exploited for acquiring 'green credits' for the overall benefit of the farmer. Use of technology and policy support are the need of the hour to improve profitability to the coconut farmer.

Acknowledgements

Sincere thanks to the Director, Central Plantation Crops Research Institute and DDG (Hort) ICAR. This work is funded by the ICAR-National Network project on Climate Change. Sincere thanks also are due to all the field and lab staff those contributed towards conduct of this research.

References

- Asseng, S., Ewert, F., Martre, P., Rötter, R.P., Lobell, D.B., Cammarano, D., Kimball, B.A., Ottman, M.J., Wall, G.W., White, J.W., Reynolds, M.P., Alderman, P.D., Prasad, P.V.V., Aggarwal, P.K., Anothai, J., Basso, B., Biernath, C., Challinor, A.J., De Sanctis, G., Doltra, J., Fereres, E., Garcia-Vila, M., Gayler, S., Hoogenboom, G., Hunt, L.A., Izaurralde, R.C., Jabloun, M., Jones, C.D., Kersebaum, K.C., Koehler, A.K., Müller, C., Naresh Kumar, S., Nendel, C., Leary, G.O., Olesen, J.E., Palosuo, T., Priesack, E., EyshiRezaei, E., Ruane, A.C., Semenov, M.A., Shcherbak, I., Stöckle, C., Stratonovitch, P., Streck, T., Supit, I., Tao, F., Thorburn, P., Waha, K., Wang, E., Wallach, D., Wolf, J., Zhao, Z. and Zhu, Y. (2015). Rising temperatures reduce global wheat production. *Nature Climate Change*, <http://dx.doi.org/10.1038/nclimate2470>.
- Ainsworth, E.A. and Long, S.P. (2005). What have we learned from 15 years of free air CO₂ enrichment (FACE)? A meta-analytic review of the responses of photosynthesis, canopy properties and plant production to rising CO₂. *New Phytologist*, 165, 351-372.
- Bhagat, R.M. Rana. And Kalia, R.S.V. (2009). Weather changes related shift in apple belt in Himachal Pradesh; in *Global Climate Change and Indian Agriculture-case studies from ICAR Network Project* (ed.), Aggarwal P K (ICAR, New Delhi Pub), pp. 48-53.

- Blum, A., Sinmena, B., Mayer, J., Golan, G. and Shpiler, L. (1994). Stem reserve mobilization supports wheat-grain filling under heat stress. *Aust. J. Plant Physiol*, 21, 771-781.
- BUR (2015). India: First Biennial Update Report to the United Nations Framework convention on Climate Change. Ministry of Environment, Forest and Climate Change, Government of India. p. 180.
- Easterling, W., Aggarwal, P.K., Batima, P., Brander, K., Erda, L., Howden, M., Kirilenko, A., Morton, J., Soussana, J.F., Schmidhuber, S. and Tubiello, F. (2007). Food fibre and forest products In: Parry M L Canziani O F Palutikof J P van der Linden P J Hanson C E (Eds) *Climate Change 2007: Impacts Adaptation and Vulnerability Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* Cambridge University Press, pp. 273-313.
- Ghannoum, O., Von Caemmerer, S., Ziska, L.H. and Conroy, J.P. (2000). The growth response of C4 plants to rising atmospheric CO₂ partial pressure: A reassessment. *Plant Cell Environ*, 23, 931-942.
- Hatfield, J.L. and Prueger, J.H. (2015). Temperature extremes: Effect on plant growth and development. *Weather and Climate Extremes*, 10, 4-10.
- Hebbar, K B., Sheena, T L., Shwetha Kumari, K., Padmanabhan, S., Balasimha, D., Mukesh Kumar. and George V. Thomas. 2013. Response of coconut seedlings to elevated CO₂ and high temperature in drought and high nutrient conditions. *Journal of Plantation Crops* 41: 118.
- Hebbar, K.B. and Chaturvedi, V.K. (2015). Impact and adaptation strategies of coconut to climate change. In Proc. of Kerala Environment Congress-2015, being held at Centre for Environment and Development, Thiruvananthapuram during May 06-08, 2015, pp. 73-78.
- IITM, (2011). Indian Institute of Tropical Meteorology. In: INCCA Report, Ministry of Environment and Forests. GOI.
- IPCC, (2013). *Climate Change 2007: Climate Change Physical basis. Summary for Policymakers* (Inter-Governmental Panel on Climate Change).
- IPCC, (2014). *Climate Change 2014: Climate Change Impacts, Adaptation and Vulnerability. Summary for Policymakers* (Inter-Governmental Panel on Climate Change).
- Kasturi Bai, K.V., Rajagopal, V., Prabha. C. D., Ratnambal. M. J. and George. M.V. (1996 a). Evaluation of coconut cultivars and hybrids for dry matter production. *J. Plantn. Crops*, 24, 23-28.
- Kimball, B.A., Pinter, P.J. Jr., Garcia, R.L., LaMorte, R.L., Wall, G.W., Hunsaker, D.J., Wechsung, G., Wechsung, F. and Kartschall, Th. (1995). Productivity and water use of wheat under free-air CO₂ enrichment. *Global Change Biology*, 1(6), 429-442.
- Kimball, B.A., Kobayashi, K. and Bindi, M. (2002). Responses of agricultural crops to free-air CO₂ enrichment. *Advances in Agronomy*, 77, 293-368.

- Muralikrishna, K.S., Naresh Kumar, S. and John Sunoj V.S. (2010). Elevated CO₂ and temperature affect leaf anatomical characteristics in coconut (*Cocos nucifera* L.). International workshop on climate change and Island Vulnerability" admat Island, U.T of Lakshadweep, 28-31 October 2010.
- Muralikrishna, K.S. (2012). Physiological response of coconut (*Cocos nucifera* L.) seedlings to elevated [CO₂] and temperature. By Ph.D Thesis submitted to Under Department of Bioscience, Mangalore University, 2007-2012.
- Muralikrishna, K.S, Naresh Kumar S. and John Sunoj. V. S. (2013). Elevated CO₂ and Temperature Affect Leaf Anatomical Characteristics in Coconut (*Cocos nucifera* L.). In: Climate Change and Island and Coastal Vulnerability (Eds- J. Sundaresan, S. Sreekesh, AL. Ramanathan, L. Sonnenschein and R. Boojh). ISBN 978-94-007-6015-8, Springer Pub. pp 141-153.
- AP Cess Fund Project: Variability in content and composition of fatty acids in coconut oil due to genetic and environmental factors. Submitted to ICAR, New Delhi-2005
- Naresh Kumar, S. (2005). Variability in content and composition of fatty acids in coconut oil due to genetic and environmental factors. AP Cess Fund Project Final Report Submitted to ICAR, New Delhi.
- Naresh Kumar, S., Govindakrishnan, P.M., Swarooparani, D.N., Nitin, C.H., Surabhi, J. and Aggarwal P.K. (2015). Assessment of impact of climate change on potato and potential adaptation gains in the Indo-Gangetic Plains of India. *International Journal of Plant Production*, 9(1), 151-170.
- Naresh Kumar, S., Pramod Kumar, A., Kumar, U., Jain, S., Swaroopa Rani, D. N., Nitin Chauhan. and Rani Saxena. (2014a). Vulnerability of Indian mustard (*Brassica juncea* (L.) Czernj. Cosson) to climate variability and future adaptation strategies. *Mitigation and Adaptation Strategies to Global Change*, 10.1007/s11027-014-9606-Z.
- Naresh Kumar S, Aggarwal, P. K., Swarooparani, D. N., Rani Saxena., Nitin Chauhan. and Surabhi Jain. (2014b). Vulnerability of wheat production to climate change in India. *Climate Research*, doi: 10.3354/cr01212.
- Naresh Kumar, S., Aggarwal, P. K., Rani Saxena., Swaroopa Rani, D.N., Surabhi Jain. and Nitin Chauhan. (2013). An assessment of regional vulnerability of rice to climate change in India. *Clim. Change*, DOI 10.1007/s10584-013-0698-3.118 issue 3-4 June 2013. p. 683 – 699.
- Naresh Kumar, S. and Aggarwal, P.K. (2013). Climate change and coconut plantations in India: Impacts and potential adaptation gains. *Agril. Syst*, <http://dx.doi.org/10.1016/j.agsy.2013.01.001>.
- Naresh Kumar, S., Aggarwal, P. K., Swaroopa Rani, D.N., Surabhi Jain., Rani Saxena. and Nitin Chauhan. (2011). Impact of climate change on crop productivity in Western Ghats, coastal and northeastern regions of India. *Current Sci*, 101 (3), 33-42.

- Naresh Kumar, S., Kasturi Bai, K. V., Rajagopal V. and Aggarwal, P.K. (2008). Simulating coconut growth, development and yield using Info Crop-coconut model. *Tree Physiology* (Canada), 28:1049–1058.
- Naresh Kumar, S. and Aggarwal, P. K. (2009). Impact of climate change on coconut plantations. In *Global Climate Change and Indian Agriculture-case studies from ICAR Network Project* (PK Aggarwal ed.), ICAR, New Delhi Pub. pp.24-27.
- Naresh Kumar, S., Rajagopal, V., Siju Thomas, T. and Cherian, K.V. (2006). Effect of conserved soil moisture on the source-sink relationship in coconut (*Cocos nucifera* L.) under different agro-climatic conditions in India. *The Ind. J. Agril. Sci*, 76(5), 277-281.
- Naresh Kumar, S. (2015). Carbon sequestration and Beyond by Plantations: Exploring scope for Added Income. In: *Agroforestry: Present Status and Way Forward* (Dhayani, SK., Newaj, R., Alam B., Dev, I eds). Biotech Books Pub., pp.193-205.
- Naresh Kumar, S., Sairam, C. V., Jose, C.T., Kasturi Bai, K.V., Palnaiswamy, C., Rajagopal, V., Krishnamurthy, K.S., Kandiannan K. and Champakam. B. (2007a.) Climate change effects on growth and productivity of plantation crops with special reference to coconut and black pepper: Impact, adaptation and vulnerability and mitigation strategies- ICAR Network Project on Impact of Climate Change on Indian Agriculture entitled Final Report, pp.21.
- Naresh Kumar, S. (2010). Assessment of Climate Change Impacts on Plantation Crops: Enabling Activity for Preparation of India's Second National Communication to UNFCCC. Final Report submitted to Ministry of Environment and Forests, Government of India. pp.48.
- Naresh Kumar, S., Singh, A.K., Aggarwal, P.K., Rao, V.U.M. and Venkateswarlu, B. (2012). Climate change and Indian Agriculture: Salient achievements from ICAR network project. IARI Pub., 32p.
- Naresh Kumar, S. (2008). Modeling impacts and adaptations in coconut to climate change in different agro-climatic zones and field response of coconut to increased temperatures and CO₂. Project Annual Report.
- Naresh Kumar, S. (2011). Climate change and Indian agriculture: Current understanding on impacts, adaptation, vulnerability and mitigation. *J. Plant Biol*, 37 (2), 1-16.
- Naresh Kumar, S. (2013). Network Project on Climate Change: Final Report, pp. 390.
- Naresh Kumar, S. and Kasturi Bai, K.V. (2009). Photo-oxidative stress in coconut seedlings: Early events to leaf scorching and seedling death. *Braz. J. Plant Physiol*, 21(3), 223-232.
- Naresh Kumar, S. (2004). Drought management in coconut gardens. (English)–CPCRI publication, pp.16.
- Naresh Kumar, S., Rajagopal, V., Siju Thomas, T., Vinu K, Cherian., Ratheesh Narayanan, M. K., Ananda, K. S., Nagawekar, D. D., Hanumanthappa, M., Vincent, S. and Srinivasulu, B. (2007b). Variations in nut yield of coconut

- (*Cocos nucifera* L.) and dry spell in different agroclimatic zones of India. *Ind. J. Hort*, 64 (3), 309-313.
- Pascual, L.M. and Tan, R.R. (2004). Comparative life cycle assessment of coconut biodiesel and conventional diesel for Philippine automotive transportation and industrial boiler application. LCA/LCM 2004, 11-24 July, 2004, LCAcentre.org.
- Peiris, T. S. G. (2006). Impact of climate change on coconut industry in Sri Lanka. Paper presented at the Third International Conference on Climate Impact and Assessment (TICCIA), 24-27 July, Cairns, Australia.
- Porter, J.R. and Gawith, M. (1999). Temperatures and the growth and development of wheat: a review. *Eur. J. Agron*, 10, 23-36.
- Rajagopal, V., Shivashankar, S., Jacob Mathew. (1996). Impact of dry spells on ontogeny of coconut fruits and its relation to yield. *Plantn. Res. Dev*, 3, 251-255.
- Subramanian, P., Dhanpal, R., Mathew, A.C., Palaniswami, C., Upadhyay, A.K., Naresh Kumar, S. and Reddy, D.V.S. (2012). Effect of fertilizer application through micro-irrigation technique on nutrient availability and coconut production. *J. Plantation Crops*, 40, 168-173.
- Sunoj, J.V.S. 2012. Biochemical response of coconut (*Cocos nucifera* L.) seedlings to elevated [CO₂] and temperature. By John Ph.D Thesis submitted to Under Department of Bioscience, Mangalore University, 2007-2012.
- Sunoj, J.V.S., Naresh Kumar, S. and Muralikrishna, K.S. 2010. Variation in total phenolic concentration in coconut (*Cocos nucifera* L.) seedlings under elevated CO₂ and temperature in different seasons International conference on climate change and environment' at CUSAT, Kochi during 24-26 October 2010.
- Sunoj, J.V.S., Naresh Kumar, S. and Muralikrishna, K.S. (2013). Variation in total phenols concentration in coconut (*Cocos nucifera* L.) seedlings under elevated CO₂ and temperature in different seasons In: Climate Change and Environment (eds: Sundaresan, J., Sreekesh, S., Ramanathan, A.L., Sonnenschen, Lenand Boojh, Ram,) Scientific Pub, 286 p.
- Sunoj, J.V.S., Naresh Kumar, S., Muralikrishna, K.S. and Padmanabhan, S. (2015). Enzyme Activities and Nutrient Status in Coconut (*Cocos nucifera* L.) Seedling Rhizosphere Soil after Exposure to Elevated CO₂ and Temperature. *Journal of the Indian Society of Soil Science*, Vol. 63, No. 2, pp 191-199.
- Sunoj, J.V.S., Naresh Kumar, S. and Muralikrishna, K.S. (2014). Effect of elevated CO₂ and temperature on oxidative stress and antioxidant enzymes activity in coconut (*Cocos nucifera* L.) seedlings. *Indian J Plant Physiol*, DOI 10.1007/s40502-014-0123-6.
- Tan, R.R., Culaba, A.B. and Purvis, R.I. (2004). Carbon balance implications of coconut biodiesel utilization in the Philippine automotive transport sector. *Biomass and Energy*, 26, 579-585.
- Roupsard, O., Bonnefond, J.M., Irvin, M., Berbigier, P., Nouvellon, Y., Dauzat, J., Taga, S., Hamel, O., Jourdan, C., Saint-Andre, I. Miallet-Serra, J.P., Labouisse, D., Epron, R., Joffre, S., Braconnier, R., Navarro, M. A. and Bouillet, J.P. (2006).

Partitioning energy and evapo-transpiration above and below a tropical palm canopy. *Agril. Forest Meterol*, 139(3-4), 252-268.

Roupsard, O., Lamanda, N., Jourdan, C., Navarro, M., Miallet-Serra J. I., Dauzat, and Tiata Siley. (2008). Coconut carbon sequestration. Part I: Highlights on carbon cycle in coconut plantations. *Coconut Res. Dev*, 24, 1-14.

Vega, E. V. (2011). Cleaner Production Opportunities for Improvement of Carbon Saving in the Production of Coconut Biodiesel, *International Journal of Chemical and Environmental Engineering*, 2 (5), 356-361.