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Chapter 3

Physiological and Biochemical Response of Coconut to Climate Change Variables

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1. Introduction

The threat of climate change is projected to be more in coastal tract and hilly areas of India where plantation crop like coconut is the predominant crop which provides sustenance to more than 10 million people and contributes Rs. 83000 million annually to the Gross Domestic Product (GDP) of the country. Coconut is grown between 20° N and 20° S latitude. It can be grown even at 26° N latitude but the temperature is the main limitation. The optimum weather conditions for good growth and nut yield in coconut are well distributed annual rainfall between 130 and 230 cm, mean annual temperature of 27 °C, abundant sunlight ranging from 250 to 350 Wm^{-2} with at least 120 hours per month of sun shine period. Since, it is humid tropical crop it grows well above 60 per cent humidity (Child 1974, Murray 1977). The climate change will affect coconut plantation through higher temperatures, elevated CO_2 concentration, precipitation changes, increased weeds, pests, and disease pressure. In this chapter the effect of climate change variables and their interaction effect on coconut growth and development and the strategies need to be adopted to combat these variables are discussed.

2. Responses to Moisture Deficit

Coconut has been considered as extravagant in water consumption. Daily water requirement is estimated between 30 and 120 L (Jayasekara and Jayasekara

1993), 55 and 115 L (Yusuf and Varadan 1993) by an adult coconut depending on soil moisture content and evaporative demand of the atmosphere. Mean E varied from 0.09 to 1.52 L day^{-1} m^{-2} leaf area in 3.5-year-old dwarf coconut palms, as estimated by measurements of xylem sap flux density (Araujo 2003). Taking the mean value of Araujo (2003) (0.8 L day^{-1} m^{-2}) and a leaf area of 140 m^2 in dwarf varieties (Ramadasan and Kasturi Bai 1999), the calculated transpirational water loss (114 L day^{-1}) agrees with the values reported by Jayasekara and Jayasekara (1993) and is only slightly higher than that reported by Yusuf and Varandan (1993) for tall varieties. Compared to the tall varieties, some evidence suggests that dwarf varieties use water more extravagantly (IRHO-CIRAD, 1992).

Drought stress affects coconut production in almost all coconut growing countries, since it is mainly a rainfed plantation (Coomans 1975; Mathes 1988; Bhaskara Rao *et al.,* 1991). Hence, the productivity is low in these areas by ~50 per cent of irrigated gardens. Coconut faces summer dry spells each year apart from the frequent occurrence of drought. Coconut plantation during the last 3 to 4 years is facing the severe threat of climate change in Karnataka, Tamil Nadu, Kerala and Andhra Pradesh which are the major coconut growing states. Lakhs of coconut trees were withered during the summer months of 2013 and 2014 in south interior Karnataka due to scanty rainfall. Almost similar fatality happened in some districts of Tamil Nadu. During the summer of 2016 vast tracts of coconut withered in Northern Kerala due to extended drought. Though some trees recover with the arrival of monsoon but the production will be affected at least for 3 years. On the other hand in the east coast of Andhra Pradesh and Odisha large number of trees was uprooted due to the cyclones. In 2015 all along the west coast, plants had scorching of leaves due to salt spray effect. This is projected to increase further as the long term climatological data for 140 years in the humid tropics of India indicate cyclic pattern in rainfall with a declining trend in annual and southwest monsoon rainfall during the past 60 years (Krishna Kumar *et al.,* 2008). Being perennial in nature, coconut palm had a long duration from the initiation of inflorescence primordia to nut maturity (~44 months) with longer pre-fertilization period (~32 months) than post-fertilization (12 months) period. Hence, the impact of drought occurring at any of the critical stages of the development of inflorescence affects nut yield (Rajagopal *et al.,* 1996; Rajagopal *et al.,* 2000) not only in current year but also in next three years to follow, thus makes the problem more severe (Naresh Kumar, 2002).

The effects of water deficit on the physiology, growth and productivity of coconut have been widely documented (Repellin *et al.,* 1994; 1997; Rajagopal and Kasturi Bai 1999; Prado *et al.,* 2001; Azevedo *et al.,* 2006; Gomes *et al.,* 2007). Compared to the tall varieties, evidence suggests that dwarf varieties use water more extravagantly due to its elevated transpiration rate (IRHO-CIRAD 1992), greater number of stomata per unit leaf surface (stomatal frequency) and lower wax content on the leaf surface (Rajagopal *et al.,* 1990), as well as a poorer stomatal control of water loss (Passos and Silva 1990). In contrast, tall varieties show a more conservative water use (Voleti *et al.,* 1993). Kasturi Bai *et al.* (1997) observed that West African Tall (WAT) behaves relatively better than the hybrids under drought conditions, due to lower g_s (0.10 mol m^{-2} s^{-1}) and, as a consequence, improved tissue water conservation.

WUE has been shown to vary among varieties of talls and dwarfs and also among ecotypes of the same variety (Prado *et al.*, 2001; Gomes *et al.*, 2002; Hebbar *et al.*, unpublished data). In a WUE study at CPCRI Kasaragod, Hebbar and chaturvedi (2015) observed that tall genotypes Kalpadhenu and FMST had high WUE under 100 per cent FC (Figure 3.1) due to their higher root biomass. On the other hand under water deficit stress dwarf maintained higher WUE due to higher stomatal conductance. Further, it was observed that talls had higher stomatal sensitivity compared to dwarfs (Figure 3.2). It indicated that both root growth and stomatal sensitivity are the important traits governing drought tolerance in coconut. Passos *et al.* (1999), comparing three dwarf genotypes, observed that Malayan Yellow Dwarf (MYD) showed better WUE than the other two genotypes (Malayan Red Dwarf, MRD and Brazilian Green Dwarf, BGD). The authors attributed the superiority to (1) higher stomatal sensitivity to changes in leaf water potential, (2) higher g_s during the rainy season, which resulted in higher P_N and better leaf cooling and nutrient uptake capacity due to transpiration, (3) a more developed root system, which leads to higher water-uptake efficiency.

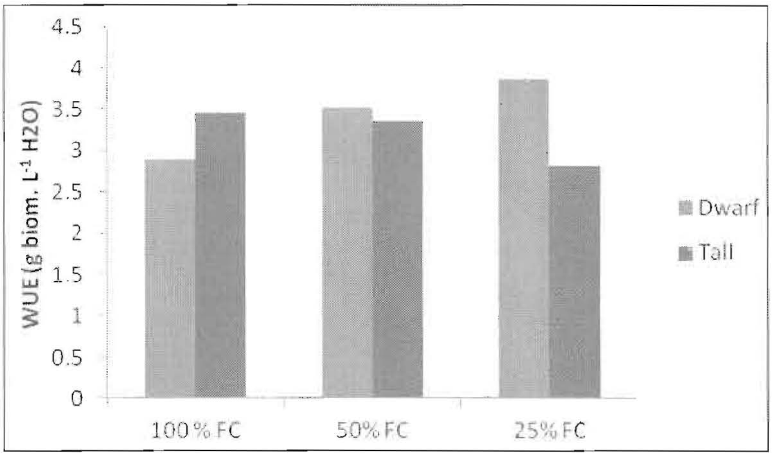

Figure 3.1: WUE of Tall and Dwarf Genotypes at different Moisture Regimes (CD at 5 per cent : 0.8).

3. Responses to Temperature Variations

Temperature influences the growth and development of all crops, shaping potential yield throughout the growing season. Current temperatures in the coastal tracts of India are optimum for production, while in east coast temperatures already exceed the optimum. The ideal mean annual temperature for coconut growing is usually considered to be in the region of 29°C (27 - 32°C), with abundant sunshine and a well-distributed annual rainfall. Temperature events higher than normal are expected to reduce coconut yield (Rajagopal and Kasturi Bai 1990). Temperature

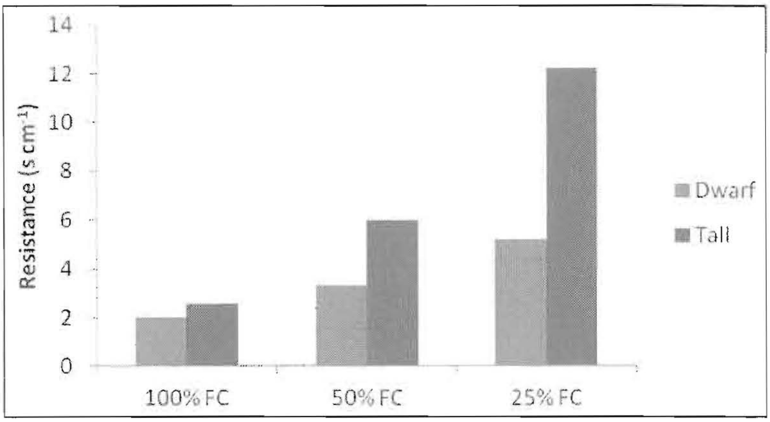

Figure 3.2: Stomatal Resistance of Tall and Dwarf Genotypes at different Moisture Regimes (CD at 5 per cent : 2.1).

can affect photosynthesis through modulating the rates of activity of photosynthetic enzymes and the electron transport chain (Sage and Kubien 2007) and, in a more indirect manner, through leaf temperatures defining the magnitude of the leaf-to-air vapor pressure difference, a key factor influencing stomatal conductance.

Crops are sensitive to HT, particularly during flowering time. High temperature can have both negative and positive impacts on growth and production in coconut. The negative impacts such as added heat stress, especially in areas at low to mid-latitudes already at risk today such as south interior Karnataka and Tamil Nadu, but they also may lead to positive impacts in currently cold-limited high-latitude regions of Assam and West Bengal. High temperature increases both photorespiration and the dark respiration and thus the total biomass production go down. Regression analysis indicated increase in T_{min} increased the leaf emergence rate: increase in T max increased inflorescence emergence rate; pistillate flower production has curvilinear relationship with rainfall/month (150mm/month-opt), nut retention has curvilinear relationship with T_{max} (32°C-opt) and T_{min} (20°C-opt). Frequent but short periods of temperature below 15°C result in fruit abnormalities such as bicarpelate nuts and lack of pollination under North Indian conditions (Naresh Kumar *et al.*, 2008).

4. Reponses to CO_2 Concentrations

In almost all plants with C3 photosynthetic pathway, such as coconut the rate of photosynthesis is limited by the atmospheric CO_2 level. For these crops, higher CO_2 will allow greater photosynthetic production. Results of thousands of studies of the effects of the increased CO_2 level on photosynthesis and crop growth are summarized in the CO_2 Science website. For most of the crops the benefit varied from 32 to 49 per cent (Idso and Idso 2000). A further benefit may result from the fact that stomatal aperture, and hence transpiration is reduced under high CO_2 (Ainsworth and Rogers, 2007). This should lead to improved water use efficiency *i.e.*, the amount of biomass produced per unit water transpired will increase and could be important for future climate when water supply is projected to be scarce.

Thus, climate change has far reaching implications for plant growth, production and food security, and approaches are required for adapting to new climates. Two primary approaches broadly exist for adapting plantation crops to these conditions: 1) improving existing crop cultivars and developing new varieties, 2) devising new cropping systems and methods for managing crops in the field. These approaches include the specific strategies discussed below.

5. Anatomical and Morphological Traits

The coconut stem acts as a water conductor and capacitor which enables it to withstand water stress was demonstrated in a study by Villalobos *et al.* (1992). The fibrous root system (homorhizic) of an adult coconut can protrude as far as 3.0 m from the trunk, but most roots reach 1.5 m in length (Avilan and Rivas 1984; Cintra *et al.*, 1992; 1993). The root growth of coconut genotypes may shift to deeper sites in response to dehydration of superficial soil layers (Cintra *et al.*, 1993). In a cropping system where vegetables, fruit trees, medicinal plants were grown coconut produced better root laterals with root hairs which are very important for the absorption of water and nutrients (Subramanian *et al.*, 2010).

Several water stress adaptive features were found in coconut leaflets. Waxy cuticle on the upper epidermis, thicker cuticle at the edge, water tissue with thin-walled cells at the upper and lower angles of the straightened leaflet margin, xylem tracheids with thick lignifications, fibrous sheet encircling seven to eight large vascular bundles in a strong midrib, and tracheids with scalariform thickening in diminutive vascular bundles (Naresh Kumar *et al.*, 2000). Drought tolerant cultivars had more scalariform thickening on tracheids and large sub-stomatal cavities.

6. Leaf Photosynthesis

Under non-limiting conditions coconut develops a large and highly productive canopy, being capable of an estimated 51 ton ha^{-1} $year^{-1}$ of total dry matter production (Foale 1993). Short-term responses of coconut to water stress such as low g_s and water potential which often impair P_N and E have been extensively documented (Repellin *et al.*, 1994; 1997; Rajagopal and Kasturi Bai 2002). Carbon assimilation rate is impaired in both tall (Reppellin *et al.*, 1997; Prado *et al.*, 2001) and dwarf genotypes (Gomes *et al.*, 2007) in response to atmospheric and soil water deficit. Reductions of P_N from 7 to 47 per cent and from 12 to 67 per cent have been reported for dwarf and tall genotypes, respectively. Drought-induced photosynthetic reductions are initially attributable to limited CO_2 diffusion from the atmosphere to the intercellular spaces as a result of stomatal closure (Reppellin *et al.*, 1994; 1997). Non-stomatal factors have been demonstrated to contribute to the reduction in P_N both during a period of severe water deficit and during the recovery phase after resuming irrigation (Gomes and Prado 2007; Gomes *et al.*, 2007). In addition, fluorescence measurements recorded by Kasturi Bai *et al.* (2006) indicated reduction in FV/Fm (photochemical efficiency) with decreasing water potential suggesting damage to photosynthetic apparatus under stress.

7. Biochemical Responses and Osmotic Adjustment

Information concerning the protoplasmic tolerance to drought stress has led to the conclusion that coconut leaves have highly efficient systems that protect cell membranes and their intracellular components. Lipid composition, lipid peroxidation level, and the activities of enzymes related to oxidative stress are good indicators of dehydration tolerance in leaves of coconut. Water deficit induced a reduction in total leaf lipid content, mainly that of the chloroplast membranes, an effect particularly expressive in the less drought-tolerant genotypes (Repellin *et al.*, 1994). In addition, an increase in the degree of lipid unsaturation in response to severe drought was also observed, which seems to be related to the maintenance of membrane fluidity, mainly in the chloroplasts (Repellin *et al.*, 1997). Coconut cultivars considered drought tolerant showed a lower level of lipid peroxidation and higher activity of catalase, superoxide dismutase, and peroxidase than cultivars empirically classified as drought susceptible. Indeed, peroxidation level was negatively correlated ($R^2 > 0.73$) with activity of antioxidant enzymes (Shivashankar *et al.*, 1991; Chempakam *et al.*, 1993). Epicuticular wax content was less in both control and drought induced plants, but increased with drought in dwarf while there was no change in talls. On the other hand super oxide dismutase (SOD) specific activity increased till 50 per cent FC and decreased with further increase in stress *i.e.* at 25 per cent FC as compared to control plants (Figure 3.3) (Hebbar *et al.*, unpublished data). It was high in FMST a drought tolerant variety.

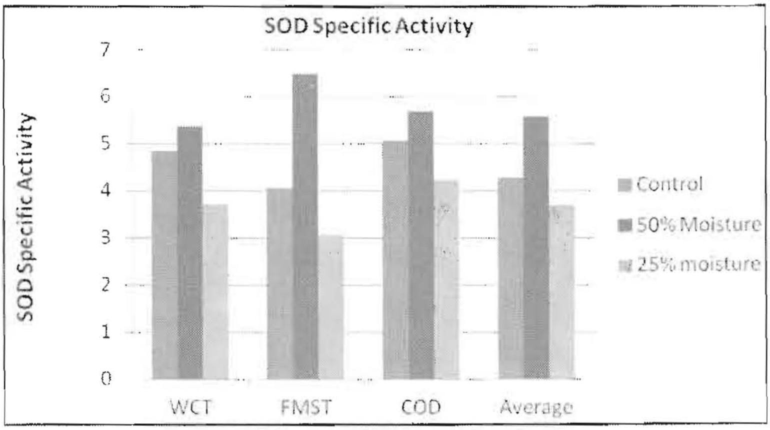

Figure 3.3: SOD Specific Activity under Induced Drought Stress.

8. Biomass Production and Water Use Efficiency

In almost all crops with C3 photosynthetic pathway, such as coconut the rate of photosynthesis is limited by the atmospheric CO_2 level. For these crops, higher CO_2 will allow greater photosynthetic production. In an Open top chamber (OTC) study at 550 and 700 ppm CO_2 biomass increased by 8 and 25 per cent respectively against ambient CO_2 concentration of 380 ppm. (Hebbar *et al.*, unpublished data). The higher growth rate of plants under elevated CO_2 was closely associated with the photosynthesis (PN). Photosynthesis was highest 14.4 at 700 ppm CO_2 as against 10.14 under ambient condition. Plants grown under [ECO_2] had higher PN to Tr ratio and thus had high WUE. However, chlorophyll fluorescence data measured in the same leaf where the PN was measured indicated that Fv/Fm (dark adapted values) which reflects the potential quantum efficiency of PSII, was on par in ambient and elevated CO_2 plants. For a given amount of water, plants under elevated CO_2 produced higher biomass and thus had higher whole plant WUE (water use efficiency). WUE was 2.53 g/litre under ambient condition and it had increased to 3.14 at 700 ppm CO_2.

9. Interaction Effect of CO_2, High Temperature and Moisture Deficits

The interaction effect of climate change variables CO_2 and elevated temperature (ET) with drought on growth and development of coconut seedlings was studied in an Open Top Chamber (OTC) at CPCRI, Kasaragod (Hebbar *et al.*, 2013b). High temperature (3°C above ambient) decreased the biomass by 10 per cent. High temperature in addition to drought had a compounded effect and reduced the biomass by 16 per cent. To certain extent the elevated CO_2 could offset the negative effect of temperature in coconut. The stimulatory effect of CO_2 under drought and high temperature was less and it could increase the biomass by only 8 per cent with 700 ppm CO_2.

Crown initiation and crown growth was slow at ET. It was only 1.3 cm/day with ET and 1.7 cm/day with elevated CO_2+ET as against 1.8cm/day of plants grown in ambient condition. Similarly, crown growth rate significantly reduced in drought plants. Leaf splitting was faster when plants were grown under elevated CO_2 and was slow with drought and ET treatments. Stomatal conductance and transpiration on the other hand were high in ET treatments 0.216 and 5.63 as against 0.125 moles/m^2/s and 2.58 moles/m^2/s with 700 ppm CO_2 respectively indicating better intrinsic tolerance of plants to water limitation under elevated CO_2 concentration. The WUE was low at ET (2.28) and increased to 2.56 g/litre ET+CO_2 indicating higher CO_2 could offset the effect of ET in coconut. Similarly, under drought too the WUE was the highest at 700 ppm CO_2 (2.70) and it was the least at ET (2.144) Hebbar and Chaturvedi 2015).

10. Strategies Adopted for Improving Existing Cultivars and Developing New Varieties

10.1. Integration of Beneficial Traits into Existing Crops through Use of Germplasm Accessions

At ICAR-CPCRI Kasaragod germplasm lines are collected from different agro-climatic zones and maintained and evaluated at International gene bank at Kidu Karnataka and used to develop cultivars adapted to climate change. There are all together 434 germplasm accessions and they have been evaluated for different biotic and abiotic stress characters. The tolerant traits are incorporated to get climate resilient varieties. Some of the drought tolerant varieties developed at CPCRI are Chandra Kalpa, Kalpatharu, Kera Keralam, Kalpa Mitra, Kalpa Dhenu, Kera Sankara, and Chandra Laksha.

10.2. Identified Germplasm/Variety and Traits that Tolerate Drought and Heat

Coconut yield drops when it experiences drought, excessive heat, deviating from the optimum for growth during key stages, including pollination, flowering, and nut development periods. Drought and heat are the important abiotic stresses affecting coconut yield.

11. Field-level Evaluations of Crop Germplasm/Varieties

To differentiate drought resistance genotypes, several selection indices have been suggested on the basis of a mathematical relationship between favorable and stress conditions (Clarke *et al.*, 1984; Huang 2000). Tolerance (TOL) (Clarke and McCaig 1982; Clarke *et al.*, 1992), mean productivity (MP) (Clarke and McCaig 1982), stress susceptibility index (SSI) (Fischer and Maurer 1978), geometric mean productivity (GMP) and stress tolerance index (STI) (Fernandez, 1992) have all been employed under various conditions. These indices have been tested at Arsikere, Karnataka which was reeling under severe drought for the years 2011, 2012 and 2013. Yield data from rainfed and irrigated coconut orchards of experimental farm at Arasikere for the genotypes as shown in the Table 3.1 (Hebbar *et al.*, unpublished data) was collected for the years 2011, 2012 and 2013 and the different indices were calculated.

Table 3.1: The Relative Yield Performance of Coconut Genotypes in Rainfed and Irrigated Conditions of Arasikere, Karnataka and the Calculation of Tolerant Indices.

Cultivar	*Coconut/Plant*		*Per cent Reduction*	*DSI*	*Geometric Mean*
	Irrigated	*Rainfed*			
WCT	52	4	92	1.14	14
LCT	63	19	70	0.86	35
ADOT	54	5	91	1.12	16
Sanramon	74	2	97	1.20	12
WCTXGBGD	180	25	86	1.06	67
BS1	44	21	52	0.65	30
PHOT	73	0	100	1.23	0
WCTXCOD	85	5	94	1.16	21
CODXWCT	72	3	96	1.18	15
TPT	62	25	60	0.74	39
Zanzibar	130	36	72	0.89	68
Java	47	20	57	0.71	31
Mean	**78**	**14**	**81**	**1.00**	**29**

The drought intensity index (DII) as calculated using the formula given by Ramírez-Vallejo and Kelly (1998) was 0.8. Values exceeding 0.7 would indicate severe drought.Schneider *et al.* (1997) showed the Geometric mean (GM) which is square root of the product from rainfed and irrigated for an individual genotype. From the above table GM was high for Zangiber and WCT x GBGD which also had high yield under stress and non-stress conditions.Ramírez-Vallejo and Kelly (1998) also concluded that the most effective approach to breed for resistance to drought would be based first on selection for high geometric mean seed yields followed by selection for low Fischer Maurer drought susceptibility index values. The Fischer and Maurer drought susceptibility index (DSI) is calculated as follows: DSI= (1-Ys/Yi)/DII(Fischer and Maurer, 1978).

Though, drought susceptibility index (DSI) was low for BSI and Java, but they were low nut production. Caution in using this index is advised as certain genotypes with the lowest DSI rankings had the lowest overall yield potential (White and Singh 1991). Small yield differences between the stress and non-stress treatments produce low DSI values even though the potential yield of the line is low. Therefore in coconut GM is the best indicator of drought tolerance under field condition and can be used in breeding programs across different environments. WCT x GBGD selected for drought tolerance had higher photosynthesis better retention of nuts under stress.

12. Devised Cropping/Farming Systems to Alleviate the Effect of Climate Change

Coconut is mostly grown in coastal and hilly areas where the rainfall is very high and the soil is poor in nutrients. The soil is sandy or laterite which has very low water holding capacity. Studies conducted at CPCRI and elsewhere indicated that coconut based farming system approach is the best adaptation strategy to overcome the effect of climate change. Appropriate, site specific cropping system management practices have been developed which help alleviate the effects of abiotic and biotic stresses on crop productivity and yield. Coconut is a tree which has no branches and grows straight vertically upwards providing more space under its canopy. Its leaves are such that it allows sun light to the crops grown under it. Between two coconut trees, fruit trees such as lime, lemon, guava, pomegranate, custard apple, cocoa, nutmeg, clove crops are planted at 15 -20 ft distance. These are medium sized crops both in height as well as canopy and can easily fit in between two adjacent coconut trees. They can be planted simultaneously or after the coconuts are established. It takes 8 to 10 years for coconut trees to start yielding properly. Whereas a number of the above mentioned crops start yielding well within 3 -5 years and last only 15 -20 years. By that time the coconut will be in its peak yield stage and will be about 20 ft high. The intercrops may be replaced by any other crop including vegetables and grasses and another cycle of medium sized intercrops can be established. Coconut farming systems have dramatic powers to stabilize eroding farmland, especially sloping lands. Practices like using nitrogen fixing perennials, ploughing, and intensive livestock rotation have fantastic soil building abilities. Plantings of useful trees can protect coastlines from damage caused by increased storm activity.

12.1. Cultural Practices, Soil Conservation and Water Management Techniques are Evolved to Manage the Drought

12.1.1. Optimize Land Use

Intensifying yields sustainably on existing arable land uses land more efficiently with better soil management. Soil management techniques like mulching of basin with coir dust at 50kg/palm, burial of husks in 3 or 4 layers, application of green manures or organic manures (FYM) at 50 to 100 kg/palm, spreading dried coconut leaves and other organic residues (mulching effect), addition of tank silt at 100 to 200 kg/palm and organic agriculture to increase soil's water retention capacity are some of the ways to improve the productivity from unit land and reduce the climate change effect. Similarly, soil conservation measures *viz.* terracing the palm basins in sloppy lands to interrupt run off of water and to enhance soil moisture, rain water harvesting: in-*situ* (land configuration, mulching etc.) and *ex-situ* (Ponds, micro water harvesting structure -jalkund *etc.*), bunding the field to prevent runoff of water. These measures would help in rainfed orchards.

12.1.2. Optimize Water-use Efficiency

With climate change, water supplies are expected to become threatened in certain regions of coconut cultivation, but water management strategies, such as drip irrigation, can conserve water and protect from water shortages. To achieve "more crop per drop", water management techniques like pitcher irrigation (bury two or three earthen pots/hollow bamboos and fill them with water to moisten subsoil), drip irrigation (two or three drippers per palm to wet subsoil layer) or if adequate water is available irrigate with 200 liters water/palm once in four days and mulching the basin with dry leaves facilitate the retention of soil moisture and achieve the "more crop per drop".

12.1.3. Use Crop Models in Decision-Making

Crop models can be used to compare crop management strategies, assist producers weigh both economic and environmental considerations as they make decisions about crop varieties, cropping dates, and management practices (Jones *et al.*, 2003 ; Hebbar et al., 2013c). Infocrop model of coconut (Naresh Kumar *et al.*, 2008) indicated that negative impacts of climate change can be overcome by adaptation strategies such as assured irrigation through drip system, soil moisture conservation, and by providing fertilizers/nutrients through organic and inorganic source in doses higher than those currently applied by the farmers (Naresh Kumar and Aggarwal, 2013). This practice in Kerala could improve the positive gains due to climate change by 7 to 21 per cent in different scenarios. Similarly, in Karnataka, West Bengal, Gujarat, Maharashtra and Odisha these practices not only off-set the negative impacts but also could result in higher yields. In North-Eastern States, providing summer irrigation and even low dose of fertilizers could further improve (in the range of 10-33 per cent) the positive impacts of climate change. Coconut plantations in islands, if managed scientifically by proper spacing, canopy management, summer irrigation and even with low dose of fertilizers the productivity could be enhanced to an extent of 2-25 per cent (Naresh Kumar and Aggarwal, 2013).

13. Coconut is an Excellent Tree Crop for Climate Change Mitigation

13.1. Carbon Sequestration and Carbon Stocks in Coconut

Plantation crops has 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. Above ground biomass in coconut varied from 15 CERs to 35 CERs depending on cultivar, agroclimatic zone, soil type and management. Annually sequestered carbon stocked in the stem is in the range of 0.3 to 2.3 CERs. Standing C stocks in 16 year old coconut cultivars in different agro-climatic zones varied from 15 CERs to 60 CERs (Naresh Kumar, 2009). C sequestration by coconut plantation is higher in red sandy loam soils and lowest in littoral sandy soils.

13.2. Coconut can Check Erosion and Wind Speed

Probably coconut is the only crop next to mangroves grows well in coastal areas. It is the best suited crop for climate change situations as it can withstand temporary water logging conditions like floods and tides with special adaptability against strong winds, storms and cyclones. It has a fibrous root system spread over few meters which not only takes up water and nutrients and anchors the plant but also helps in checking the erosion in high rainfall areas. Coconut orchards also act as strong wind breaks and reduce storms and cyclones.

14. Strategies for the Future

The existing scientific knowledge can address to adapt cropping systems to climate change in the short-term. However, uncertainties and limited predictability in the long-term require an infrastructure that drives innovation and implements crop adaptation strategies in a sustainable manner. In particular, research investments and efforts are needed to further:

- ☆ Understand the physiological, genetic, and molecular basis of adaptation to drought, heat and biotic stresses likely resulting from climate change;
- ☆ Develop region specific farming models that integrate genetic and management technology.
- ☆ Give more thrust on value addition to avoid volatile price and stability in income.
- ☆ Translate new knowledge into new agricultural systems that integrate genetic and management technologies (*i.e.*, both breeding and agronomy will contribute to adaptation); and
- ☆ Transfer knowledge effectively and make technologies and innovations widely available to increase food production and stability.
- ☆ Ensure effective collaboration and communication between both public and private sector research and development to create knowledge, and develop and transfer new technologies. Although the contributions of government, universities, and industry may vary with crop, region, and

time, the roles of each can be tailored to develop crop varieties, cropping systems, and agricultural management strategies appropriately.

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