IMPACT OF CLIMATE CHANGE ON COCONUT, ARECANUT AND COCOA AND ADAPTATION STRATEGIES

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The effect of climate change on plantation crops is manifested through elevated temperatures, changes in precipitation pattern, sea level rise, cyclone and flooding. Temperature has been increasing and rainfall decreasing significantly since 1980s in tune with the global warming especially across the high ranges, followed by the low lands and coastal areas where coconut and arecanut is predominantly grown with cocoa as an understorey crop. Between 2010 and 2016 coconut and arecanut faced severe drought and lakhs of trees withered in south interior Karnataka, and Tamil Nadu. Almost similar conditions have occurred in some districts of Kerala and Andhra Pradesh due to extended drought. This was further aggravated under the prevailing high temperature and led to severe nut fall both in coconut and arecanut. Rise in T_{min} during the months of January and February is critical for arecanut. On the other hand in the east coast of Andhra Pradesh, Orissa and Tamil Nadu large number of trees were uprooted due to the cyclones. In 2018 alone cyclone Titli and Gaja uprooted 11 and 50 lakh coconut trees in AP and TN respectively. All these climate adversaries severely affect the production for a long period of time impacting the livelihood of millions. Therefore sustainable production approaches are required for adapting to new climates.

Coconut is grown between 20 N and 20 S latitude. More than 90% of the area is occupied in four southern states of Kerala, Karnataka, Tamil Nadu and Andhra Pradesh. 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. Another important commercial palm is arecanut mostly concentrated in western ghat hills and plains of Karnataka and Kerala. Arecanut grows within 28 North and South of equator. Even though the crop can be grown at altitudes of 1000 msl, it is seen that the quality of the nut deteriorates as altitude increases. The temperature range of 14C-36C is optimum for better growth of arecanut. The microclimate of arecanut and coconut plantations is congenial for cocoa cultivation in India. Cocoa is grown predominantly in Karnataka and Kerala but rapidly spreading in Andhra Pradesh and Tamil Nadu. Cocoa can be successfully grown up to 30[illegible] msl. However, it can be grown up to 1100-1200 m altitude. Cocoa can tolerate a mean monthly maximum temperature up to 33C and the optimum range is 30-32C. The temperature in most of the cocoa growing areas lies between a maximum of 30-32C and a minimum of 18-21C. High temperature reduces the pod growing period and in turn the yield and bean size.

Climate change and climate change projections for India

The Inter-Governmental Panel on Climate Change Report (2014), projected the increase in global mean temperatures during 1951-2010 period by 0.6-0.7°C out of which natural variability contributed to ± 0.1°C change in temperature. The analysis by Indian Institute of Tropical Meteorology, Pune indicated that in Indian region also annual mean maximum temperatures increased by about 0.71 C in past 100 years. The rate of increase in maximum temperature has been at a rate of 0.17 C /10 years while the corresponding increase in minimum temperature has been 0.29 C/10 years. During

1871-2014 period, India faced 27 deficit and 20 excess monsoon years (IITM 2011). Out of these, as many as 15 deficit monsoon years and 6 excess monsoon years fell in post 1960 period. The threat of climate change is projected to be more in coastal tract and foot hills of Western Ghats of India where plantation crops are the predominant crop (Naresh Kumar et al., 2011; Naresh Kumar and Aggarwal 2013; Hebbar et al., 2016a; Hebbar et al., 2016b).

Reponses to CO_2 concentrations

Coconut seedlings exposed to elevated CO_2 [ECO_2 550 and 700 μmol mol^{-1}] for three years in an open top chamber (OTC) benefited their growth and development as they assimilated more carbon dioxide, due to higher photosynthetic rates and larger leaf area, resulting in significant increase in shoot and root biomass. The leaf water balance was maintained by thicker cuticle, by reduced stomatal density and by regulation of stomatal conductance. The growth of seedlings in OTC with elevated temperature up to 3°C above 31°C (the annual mean maximum temperature of experimental site) was significantly reduced consequent to the reductions of leaf area (>50%), chlorophyll content (>40%) net photosynthesis as compared to control. However, there was higher deposition of epicuticular wax on the leaves (Muralikrishna 2012; Hebbar et al., 2013; Muralikrishna et al. 2013). Cocoa seedlings under [ECO_2] had grown tall and also produced significantly high biomass. The biomass increase in cocoa was 29% at 700 ppm CO_2 (Sujatha et al. 2016) (Fig.1)

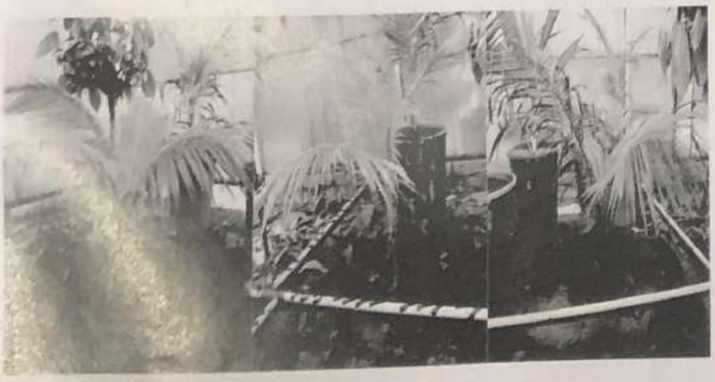

Fig. 1. Response of coconut seedling to high temperature; (a) Control (b) Ambient +3°C (c) 550 ppm CO_2 + Ambient +3°C

High temperature

High temperature can have both positive and negative impacts on growth and production (Hatfield and Prueger 2015). The negative impacts such as added heat stress especially in areas at low to mid latitudes (Eastern Tamil Nadu) already at risk today but also may lead to positive impacts in currently cold limited high latitude regions (NE). In seedlings, high temperature increases both photorespiration and dark respiration in addition to decreasing photosynthesis thus the total biomass production goes down. Palms like coconut and arecanut are highly sensitive. In an OTC study with elevated temperature of 3°C from ambient, the Pn of coconut seedlings reduced to 2.5 from 5 u mole m^{-2} $s^{-1}$of ambient grown seedlings (32 to 34°C). Similar decline was seen in cocoa too, but the negative effect of temperature to certain extent was alleviated with [ECO_2] treatments.

Pollination is one of the most sensitive phenological stages to temperature extremes. In coconut, cultivar variation existed for cardinal temperatures (T_{min}, T_{opt} and T_{max}) of pollen germination percentage and pollen tube growth. Mean cardinal temperatures calculated from the bilinear model for the genotypes ranged from 23.5 °C to 29.5 °C, 9.7 °C to 16.5 °C and 40.1°C to 43.9 °C for T_{opt}, T_{min} and T_{max}, respectively. In general tall cultivars WCT, LCT, FMST, dwarf cultivar COD and hybrids showed better adaptability to high temperature while dwarf MYD was the least adaptable (Hebbar et al., 2018) (Fig.2).

Fig.2. Differences in coconut pollen germination at 25 oC (left) and 40oC (right)

Precipitation

The long term analysis of 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. As most of the plantation crops except arecanut and oil palm are rainfed, their productivity is ~50% low in these areas compared to that of plantations grown in irrigated gardens. 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 has been affected at least for 3 years. Being perennial in nature, coconut has a long duration between its juvenile and adult stage and hence, the impact of drought occurring at any of the critical stages of the development will be high. High rainfall (5610 mm in 1994) with high intensity rains results in spread of fruit rot (*Phytophthora palmivora*) and water stagnation leading to yield reduction in arecanut (Sunil et al., 2011). On the other hand the rainfall has positive impact on cocoa. Cocoa escapes heavy monsoon rains during pod development stage (Zuidema et al., 2005).

Interaction effect of CO_2, high temperature and water deficit

In OTC experiments it was observed that there was significant reduction in biomass due to both high temperature as well as water deficit. However, under combined water deficit and elevated CO_2 conditions the biomass reduction was less suggesting coconut would produce more biomass in the future climate with the present level of soil moisture. However, both under normal and water limited conditions there was reduced stomatal conductance and transpiration with elevated CO_2. Thus, the water requirement to produce unit biomass in ECO_2 treatment is less. However, with the projected reduction in precipitation under future climate the biomass production and nut production may be reduced unless corrective measures are taken. Similar to the above ground biomass below ground biomass i.e, root biomass too increased with elevated CO_2. Thus, it is expected that there will be higher carbon sequestration under future climate which is an important alternative available to mitigate the climate change effect.

Salt effect

According to recent projections, global mean sea level could rise as much as 32 cm in the next 40 years and rise 75 to 190 cm over the next century. At least two thirds of coconut plantations are located in coastal zones and the majority of coconut growing countries are islands. Coconut is being exposed to increasingly frequent phenomena of high tidal swell and saltwater incursions from the ocean in the recent times resulting in salt effect. Therefore it is important to conserve the salt tolerant germplasm for the future climate. Salt spray is another phenomenon, generally occurs during the commencement of monsoon in west coast. Commencement of monsoon starts with gusty winds which brings tiny droplets of salt to the sea shore and adjoining areas and deposit on the plants. If there is no or low rainfall it causes high salt injury which may be destructive for coconuts. Coconut is moderately tolerant to salt spray and hence it mitigates the salt spray effect on other sensitive crops in the sea shore.

Climate change and pest

Crop pathogen interactions may also be influenced by overall temperature rise thus speeding up the pathogen growth rates, increasing reproductive generations per cycle, decreasing pathogen mortality rate and by making the crop more vulnerable. The emergence of two new pests viz., palm aphid and whitefly in arecanut is a consequence of either climate change or pest resurgence in perennial ecosystem (Josephrajkumar et al. 2013). In Andhra Pradesh incidence of slug caterpillar happens during the summer months (April – May), causing severe defoliation and reduction in yields of coconut and oil palm. The insect-crop relations are also indirectly modified with elevated CO_2; increased C:N ratio in crop leaves renders them less nutritious per unit mass and further stimulates increased feeding by insects, leading to more plant damage. High rainfall with high intensity rains results in spread of fruit rot (*Phytophthora palmivora*) leading to yield reduction in arecanut.

Adaptation strategies

In plantation crops, management of crop becomes very important during adverse conditions in order to sustain the productivity (Naresh Kumar 2010; Naresh Kumar et al. 2012). 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 (Fig. 3).

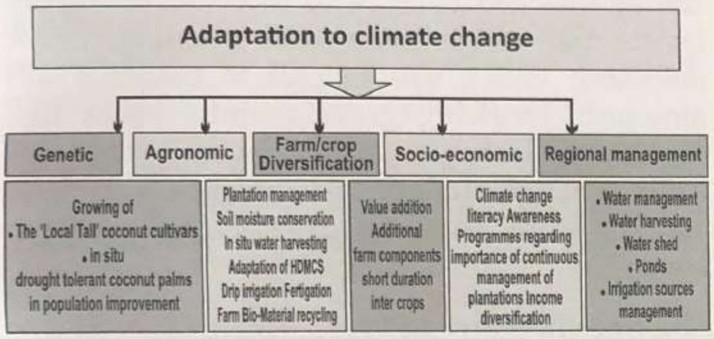

Fig. 3. Framework for adaptation of plantation crops to climate change

Site specific and need based adaptation strategies are required for the sustainable production under future climate. In places where positive impacts are projected, current poor management may become a limiting factor in reaping the benefits of CO_2 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 production across the agro-climatic regions.

Strategies adopted for improving the existing cultivars and developing new varieties:

Integration of beneficial traits using germplasm accessions

Plantation crops have rich source of germplasm accessions and they have been evaluated for different biotic and abiotic stress characters. For example in coconut there are all together 434 germplasm accessions. Similar collections are available in other plantation crops. The tolerant traits are incorporated to get climate resilient varieties. Some of the drought tolerant varieties developed in coconut are Chandra Kalpa, Kalpatharu, Kera Keralam, Kalpa Mitra, Kalpa Dhenu, Kera Sankara, and Chandra Laksha.

Germplasm/variety for traits such as tolerance to drought and heat

Utilization of *in situ* identified drought tolerant plants in population improvement programme is very important for making the crop more resilient to climate change conditions. Drought and heat are the important abiotic stresses affecting yield. WUE (water use efficiency) has been shown to vary among varieties/genotypes and considered as one of the important traits to identify and select drought tolerant genotypes. WUE in coconut is found to be regulated by both efficient water uptake by root systems as well as controlled water loss through better regulation of stomatal movement. Tall genotypes Kalpadhenu and FMST had high WUE due to better root system. Stress tolerant plants in addition to possessing higher photosynthesis, accumulated more epicuticular wax on the leaves for better conservation of moisture.

Pollination is one of the most sensitive phenological stages to temperature extremes. *In vitro* pollen germination showed wide variation for cardinal temperatures (T_{min}, T_{opt} and T_{max}) of pollen germination percentage and pollen tube growth. Mean cardinal temperatures ranged from 23.5 °C to 29.5 °C, 9.7 °C to 16.5 °C and 40.1°C to 43.9 °C for T_{opt}, T_{min} and T_{max}, respectively. In general tall cultivars WCT, LCT, FMST, dwarf cultivar COD and hybrids showed better adaptability to high temperature while dwarf MYD was the least adaptable. It is a simple technique to select temperature tolerant genotypes to climate vulnerable regions and the pollen parameters identified in the present study can be used as one of the parameters in the breeding program to develop new hybrids for areas that are vulnerable to heat stress.

Cropping/farming systems to alleviate the effect of climate change.

In coastal 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 cropping/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. Adaption of cropping system and integrated farming approaches is very important to combat the risks of monocropping and climate change.

Palms such as coconut and arecanut trees do not have branches and grow straight vertically upwards providing more space under their canopy. Their leaves are such that it allows sun light to the crops grown under it. Between two 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 palm trees. It takes 8 to 10 years for palm trees to start yielding stably. Whereas a number of the above mentioned crops start yielding well within 3 -5 years and last only 15 -20 years. Later, the intercrops may be replaced by any other crop including vegetables and grasses and another cycle of medium sized intercrops can be established. 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.

Cultural practices, soil conservation and water management techniques to manage the drought
Optimize land use

Soil management techniques like mulching of basin with coir dust @50kg/palm, burial of husks in 3 or 4 layers, application of green manures or organic manures (FYM) @ 50 to 100 kg/palm, spreading dried coconut leaves and other organic residues (mulching effect), addition of tank silt @ 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.

Optimize water-use efficiency

To achieve "more crop per drop", wate management techniques like pitcher irrigation (bur two or three earthen pots/hollow bamboos and fi them with water to moisten subsoil), drip irrigatio (two or three drippers per palm to wet subsoil layer or if adequate water is available irrigate with 20 liters water/palm once in four days and mulching th basin with dry leaves facilitate the retention of soi moisture and achieve the "more crop per drop (Subramanian et al., 2012). The basin area of plant can be mulched either with green leaves or dr leaves and weeds soon after planting. Black polythene mulch was helpful to conserve soi moisture. Growing green manure crops like *Glyricidia*, *Sesbania*, sunhemp and cover crops between two rows of trees have potential to improve soil moisture retention capacity and nutrien content. .

Site-Specific Nutrient Management (SSNM)

The SSNM is critical for green house gases (GHG mitigation so as to reduce input cost and enhan nutrient use efficiency considerably. This approa facilitates grower to invest only on deficie nutrients and omit nutrient application which was sufficient range in soils. Various benefits of SSN practice include lowering in input cost, high nutrient use efficiency, and reducing GH particularly N_2O. It substantially improves bo nutrient and water use efficiency.

Plantation crops are excellent tree crops f climate change mitigation

Most of the plantation crops are trees and have lor life span and hence store large amount of carbon their vegetation. Annual C sequestration in cocon above ground biomass varied from 15 to 35 CO_2/ha/year depending on cultivar, agro-climat zone, soil type and management. Annuall sequestered carbon stocked in to stem is in the rang of 0. 3 to 2.3 t CO_2/ha/year. Standing carbon stock in 16 year old coconut cultivars in different agro-climatic zones varied from 15 to 60 t CO_2/ha/year Annual carbon sequestration by coconut plantation is higher in red sandy loam soils and lowest in littoral sandy soils (Naresh Kumar 2007) Productivity per unit area of land can be increased by adopting high density multi species cropping system (HDMSCS). Annual increments in biomass or net primary productivity ranged from 1.38-2.66t ha^{-1} in cocoa and 3.34-7.11 t ha^{-1} in areca. Parallel to these, CO_2 sequestration ranged from 2.02-3.89 and 5.14-10.94 in cocoa and areca respectively

Conclusion

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.

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