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Climate change: Response, adaptation strategies and mitigation potential of Coconut, Arecanut and Cocoa

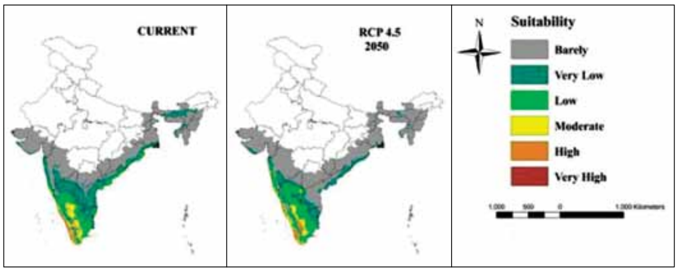
Coconut, arecanut and cocoa are the major plantation crops grown along the coast and hilly tracts of India, and are highly vulnerable to changing climatic factors. Most of these crops require an optimum temperature of 29±3°C for their growth and production. As per the climate change model projection, the temperature of the growing region is expected to increase by 1.6 to 2.1°C by 2050 and 2.1 to 3.2°C by 2070 for RCP 4.5 and RCP 8.5, respectively, without a significant change in precipitation. This precarious situation will likely expose the plants to both high temperature and temperature-induced drought. Thus, these two climatic factors decide the crop vulnerability of a region presently under cultivation and the emergence of alternate areas likely to be suitable under future climate. While the west coast of India has been found suitable, the south interiors of Karnataka and Tamil Nadu, as well as the east coast and north-east, are likely to become less suitable and hence require adaptive strategies for their sustainable cultivation. Sustenance of trees like coconut, arecanut and cocoa contributes not only to the livelihood of the growers but also has a significantly high C-sequestration potential and can sequester carbon for longer periods of more than 30 years, thus mitigating the climate change effect to a certain extent.

PLANTATION crops are grown in coastal belts and hilly terrains between 8.4°N and 20°N latitudes besides north-east regions of India. In India, coconut is cultivated in an area of 2.1 m ha and occupies the entire coastal belt. The major area share goes to Kerala, Karnataka and Tamil Nadu, followed by Andhra Pradesh, Goa, Maharashtra, and Odisha and to a small extent to North-east. The long spells of hot and dry weather, severe winters and extremes of temperatures are considered unfavourable for coconut. The west coast of Karnataka and Kerala is humid, and the maximum temperature (T_{max}) reaches only 34 to 36°C, while on the east coast of Tamil Nadu, Andhra Pradesh and Odisha, the climate is dry, and T_{max} reaches as high as 42 to 44°C. In the south interior parts of Karnataka (Tumkur, Hasana, Ramanagara) and Tamil Nadu (Coimbatore, Theni, Erode), a major coconut belt, the weather is dry, and T_{max} reaches up to 38°C to 40°C, and the humidity is low. This region is mainly rainfed, and precipitation is a major production constraint. Arecanut is grown in high rainfall areas such as the Malnad region of Karnataka (≥ 2500 mm) and low rainfall areas like the plains of Karnataka or parts of the Coimbatore district in Tamil Nadu (750 mm). Like coconut, arecanut also requires high humidity for its optimum growth. High rainfall during the nut development stage (June to July) reduces the yield. T_{max}, T_{min}, rainfall and relative humidity (RH) are attributed to more than 97% variation in arecanut yield. In India, cocoa is grown as a mixed crop in arecanut, coconut and oil palm gardens. It is cultivated mainly in the states of Kerala and Karnataka, and its cultivation is gaining increasing popularity in Tamil Nadu and Andhra Pradesh.

IPCC (2014) projections of climate models reveal that the temperature of plantation crop-growing regions is likely to be increased to the tune of 1.1°C to 2.6°C by the end of the 21st century without much change in the precipitation. The elevated temperatures are correlated with higher vapour pressure deficit and evaporative driving forces.

Impact of climate change

As plantation crops are grown across different agro-ecological zones of India, evaluating the impacts of climate change scenarios will help understand the relationships between crop niches and the corresponding environment, priority cultivation areas, and planning adaptation strategies. We used the species distribution model MaxEnt to predict the change in the climate of some of the plantation-growing areas. Bioclimatic variables Bio 4 (Temperature seasonality, 34.4%) and Bio 7 (Temperature Annual Range, 28.7 %) together contributed 63.1%, which along with Bio 15 (precipitation seasonality, 8.6%), determined 71.7% of climate suitability for coconut in India. At all India level, the model had predicted 15% of the total area suitable for coconut under the current climate under the category 'high suitable' all along the

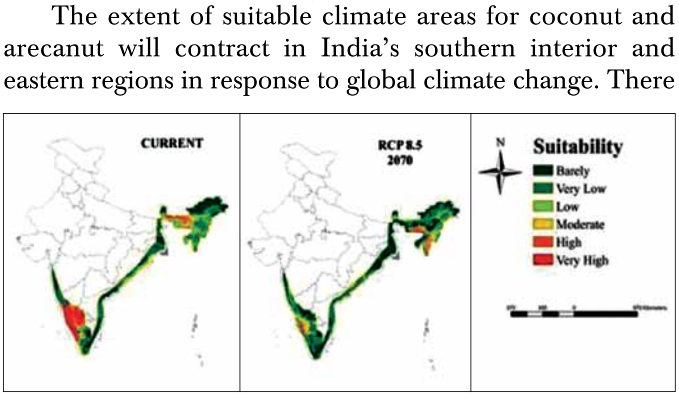


Climatically suitable areas for coconut production in India under current and future climates of the 2050s for RCP 4.5 as modelled by MaxEnt

west coast (Karnataka and Kerala), 'moderate suitable' in some parts of south interior Karnataka and Tamil Nadu. In contrast, the rest of the south interior is 'low suitable', and the eastern region (Tamil Nadu, Andhra Pradesh, Odisha, West Bengal) and North-eastern states are 'low to very low suitable'. Under the future scenarios, climate suitability for coconut all along the west coast was high. In the south interior, the climate of some of the current areas of high probable occurrence may change into 'moderate suitable', 'moderate to less suitable' and 'less suitable' to 'unsuitable'. In the East region, cultivation of these plantation crops is 'less suitable'. South interior regions are low rainfall areas; hence, the temperature-induced rise in evapotranspiration (ET) might subject the palms and cocoa to drought in areas without irrigation facilities. The prevailing low humidity further exasperates this during the summer months.

Similar to coconut, arecanut distribution was influenced by Bio19 (Precipitation of the coldest quarter, 27.3%), Bio 7 (Temperature annual range, 20.5%), Bio 15 (Precipitation seasonality, 13.9%), and Bio 1 (Annual mean temperature, 13.7%), and these variables together contributed >75%. Karnataka occupies more than 50% of the area. South interior Karnataka, where currently there is extensive cultivation of arecanut, the climate under future scenarios may likely become 'moderate to low suitable', especially in the districts of Chitradurga, Davangere, Shimogga, and parts of Tumkur. Similarly, in Kerala, northern districts which are found to be currently 'highly suitable' are likely to become 'low suitable'. In the north-east, the climate of Assam, which is 'high suitable' at present, may become 'moderate to low suitable'. At the same time, adjoining states of Meghalaya and Tripura may emerge as new climatically suitable areas.

The extent of suitable climate areas for coconut and arecanut will contract in India's southern interior and eastern regions in response to global climate change. There is a shift in climate suitability from 'high to moderate', 'moderate to low' and 'low to unsuitable' under future climate. Effective coordination amongst all stakeholders is indispensable for developing and implementing adaptation strategies to ensure sustainable cultivation of coconut and arecanut, at least in areas where it is cultivated predominantly. Since cocoa is grown as an understory crop in coconut, arecanut and oil palm plantations, sustained cultivation of these crops would ensure cocoa cultivation. Various agro-climatic techniques, which have been used to phenotype and effectively manage some of the risks posed by climate change to plantation crop productivity, are discussed below.



Climatically suitable areas for arecanut production in India under current and future climates of the 2070s for RCP 8.5 as modelled by MaxEnt

Adaptive strategies

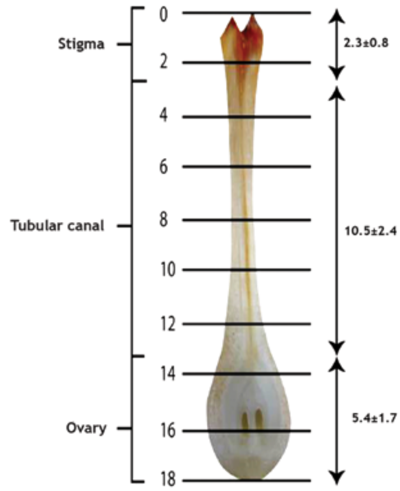
Germplasm/variety and adaptive traits to tide over drought: Genetic improvement is the most important aspect of sustaining coconut productivity, particularly in areas identified as vulnerable to climate change. Growing of the 'Local Tall' coconut cultivars [e.g. WCT and LCT (for the west coast), Tiptur Tall (for Karnataka), Sakhi Gopal Tall (for Odisha), ECT (for Andhra Pradesh)] in areas prone to water scarcity is a viable option. Utilization of identified *in situ* drought tolerant coconut palms in population improvement programmes is vital for developing resilient crop genotypes.

Extensive research work carried out on coconut led to the development of screening methods for the identification of drought tolerant genotypes. Some drought tolerant varieties/hybrids are WCT, LCT, FMST, WCT × COD, LCT × GBGD, and LCT × COD. Hybrids (LCT × GBGD, LCT × COD, WCT × COD) and the talls (JVGT, FMST, PHOT and CCNT) show higher epicuticular wax (ECW) content than the other cultivars, including dwarfs. The transpiration (E) is inversely proportional to the ECW content on the leaf surface.

Climatic factors influencing whole plant water use efficiency (WUE) of coconut seedlings: Hydroponically grown coconut talls and dwarfs exhibited wide variability in their response to vapour pressure deficit on the leaf surface (VPDL) caused by high temperature and low humidity. VPDL directly influenced water consumption of the plant per day and stomatal regulation. At high VPDL, talls close their stomata, and this sensitivity enabled them to conserve water and maintain significantly high WUE. In contrast, dwarfs stomata were insensitive, allowing greater water loss without a concomitant increase in biomass resulting in low WUE. Further in dwarfs, the early photosynthetic light saturation at 1400 μ mole photon/m^2/s makes them less efficient biomass accumulator under high light intensity. At high temperature and low humidity in general, coconut WUE is low, and especially dwarfs are more sensitive and hence are not suitable for those regions with dry weather or regions expected to become dry under future climate scenarios.

Response to high temperature: High temperatures can have both negative and positive impacts on growth and production. The negative impacts such as added heat stress, especially in areas at low to mid-latitudes which are already at risk today, such as south interior Karnataka and

Coconut seedlings aged two and eight months in a hydroponic system. Dwarf variety CGD (Left) and tall variety Kalpa Prathibha (Right); Plants are evaluated for the effect of climatic factors on WUE



Longitudinal section of the pistil of coconut variety WCT. The cross lines from 0-18 indicate the length in mm (mean±SD) of the stigma, tubular canal and ovule bearing region

Tamil Nadu and all along the east coast, but may also lead to positive impacts in currently cold-limited high-latitude regions of Assam and West Bengal. High temperature increases both photorespiration and dark respiration; thus, the total biomass production is severely affected in seedlings. In adult palms, 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 temperatures, while dwarf MYD was the least adaptable. It is a simple and useful technique to select temperature tolerant genotypes for climate vulnerable regions. 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 vulnerable to heat stress.

Further, studies on the progamic phase of the tall coconut cultivar West Coast Tall (WCT) revealed that it has a pistil length of 18.2 ± 4.9 mm and at 29°C pollen tube took four days to reach the ovule. At high temperatures ($T_{max} > 33$°C), pollen tube growth through the pistil is significantly reduced, making it incapable to reach the ovule on time which affect fertilization. High temperature also advances nectar secretion and stigma receptivity, and the change in the phenology affects the visit of insect pollinators. Thus, poor pollination and the inability of pollen tubes to reach the ovule on time to effect fertilization could cause poor nut set in the coconut under high temperature.

Interaction effect of elevated CO_2 [ECO_2], high temperature and drought on water use efficiency (WUE): In open top chamber (OTC) experiments, the stimulatory effect of CO_2 on the growth of coconut and cocoa seedlings was observed. ECO_2 could ameliorate the negative effect of high temperature and water deficit stress to a certain extent. Under normal and water-limited conditions, there was reduced stomatal conductance and transpiration with ECO_2. Thus, the water required to produce unit biomass in ECO_2 treatment is less. This indicates that coconut would produce more biomass under future climate at the present level of moisture available. But coconut response to ECO_2 was stronger under normal conditions than under water-limited conditions, suggesting an additional advantage of ECO_2 to coconut is less under drought. However, the response of cocoa seedlings to ECO_2 in improving WUE was high under water deficit conditions compared to plants under normal conditions suggesting an additional advantage of ECO_2 to cocoa under water-limited conditions.

Salinity stress: The global mean sea level could rise as much as 32 cm in the next 40 years and 75 to 190 cm over the next century. At least two-thirds of coconut plantations are located in coastal zones, and most coconut-growing countries are islands. In recent times, coconut has been exposed to increasingly frequent phenomena of high tidal swell and saltwater incursions from the ocean resulting in the salt effect. Therefore it is important to conserve the salt-tolerant germplasm for future climate. Coconut is only moderately tolerant to salinity, and a dwarf variety MGD (Malayan Green Dwarf) could tolerate up to 8.3 dS/m EC. Talls are expected to better tolerate these conditions than dwarfs. This understanding will help make appropriate strategies for managing coconut, grown at coastal systems in the face of rising sea levels under climate change.

Salt spray is another phenomenon that generally occurs during the commencement of monsoon on the west coast. Commencement of monsoon starts with gusty winds, which bring tiny salt droplets to the sea shore and adjoining areas, and deposit them on the plants. If there is no or low rainfall, it may cause high salt injury and be fatal. Coconut is moderately tolerant to salt spray; hence, it mitigates the salt spray effect on other sensitive crops on the sea shore.

Cropping/farming systems to alleviate the effect of climate change

In coastal areas, the rainfall is very high, and the soil lacks nutrients. The sandy or laterite soil has a very low water holding capacity. In hilly areas, there is a problem of erosion. Studies conducted at ICAR-CPCRI and elsewhere indicated that the coconut and arecanut-based farming system approach is the best adaptation strategy to overcome the effect of climate change. The fibrous root system of the crop not only helps to check the erosion but also improves the soil organic matter content over the years.

Coconut and arecanut have no branches and grow straight vertically upwards, providing more space under their canopy. The phyllotaxy of these crops allows more sunlight to the understorey crop. Between two coconut trees, fruit trees such as lime, lemon, guava, pomegranate, custard apple, cocoa, nutmeg, and clove crops are planted at a 15-20 ft distance. These are medium-sized crops in height and canopy and can easily fit 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 commence the economic yield, whereas a number of the crops mentioned above start yielding well within 3-5 years and last only 15-20 years. By that time, the coconut is at its peak yield stage and 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. Annuals or biennials like turmeric, ginger, elephant foot yam, tapioca, dioscorea, sweet potato, etc. are grown in the inter-space as arecanut-based intercropping systems. Perennials like banana, cocoa, pepper, and betel vine are the best-mixed cropping systems in arecanut orchards.

Cultural practices, soil conservation and water management techniques

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 @ 50 kg/palm, the 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), the 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, rainwater harvesting: *in situ* (land configuration, mulching etc.) and *ex situ* (Ponds, micro-water harvesting structure-*jalkund*, etc.), bunding the field to prevent run-off of water would help in rainfed orchards.

Optimize water-use efficiency: With climate change, water supplies are expected to threaten certain coconut and arecanut cultivation regions. Still, water management strategies, such as drip irrigation, can conserve water and protect from water shortages. An adult coconut palm bearing 100 nuts per year would require around 80 litres of water per day when the VPD (vapour pressure deficit) is around 2.5Pa. 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 to rinse with 200 litres 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".

Mitigation potential

Plantations are highly suitable for mitigating greenhouse gas emissions because of high carbon sequestration potential, air purification by O_2 release, acting as a source of biofuel and energy, and micro-climate modification.

Plantations like coconut, arecanut and cocoa have a significantly high C-sequestration potential for longer periods of more than 30 years. Coconut can sequester quite a high amount of 15 tonnes CO_2 ha/year, arecanut 7 tonnes CO_2 ha/year and cocoa 1 to 2 tonnes CO_2 ha/year. Even if one lakh per hectare additional area of coconut, arecanut and cocoa are planted, it would sequester 23 lakh tonnes of CO_2 year, which is approximately 0.08% of the total GHG emissions from India in 2019. Total GHG emissions from India in 2019 were 2,880 million tonnes of CO_2 eq. Though a little, quite significant quantum of sequestration is possible from a small area. Sequestration could be further enhanced by adopting the high-density multiple cropping systems.

CONCLUSION

The study clearly shows that the impact of climate change on the plantation is site specific. Some of the presently high suitable climate regions may become moderate or less suitable, while a small portion on the west coast and north-east may become high suitable. Accordingly, newer plantations should include tolerant varieties while, areas which are already planted and becoming climate unsuitable, require adaptive strategies for the sustenance of the crop. Hence the future research priority should be:

- To phenotype the diverse genotypes for drought, high temperature, flooding and salinity tolerance;
- Evolve tolerant genotypes either through selection or breeding approaches with wider adaptability;
- Create awareness for farmers to follow the site-specific cropping system models developed by the Research Institutes and AICRP centres which conserve the soil moisture and alleviate high-temperature effects to a certain extent;
- Value addition and product diversification for better income;
- Market-linkage and cooperative initiatives; and
- Income insurance safety nets such as crop insurance.

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