Chapter 11
Impact of Climate Change on Tropical Fruit Production Systems and its Mitigation Strategies

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Abstracts Scientists are almost of unanimous opinion that tropics will be the first and most to suffer due to climate change even though the magnitude of projected change as well as past climate trend is moderate as compared to other part of the world. Reasons are though complex, include poor economic conditions of majority of population, higher dependence on natural resources and ecosystem service and relatively narrow temperature ranges. Projection of climate change for tropics indicates rise in temperature of 0.4–1 °C, 0.8–3.2 °C and 1.2–6 °C by the 2020, 2050 and 2100 respectively as compared to base line period (1961–1990). Atmospheric CO_2 concentration is likely to reach 550–800 ppm from the present level of 400 ppm by the end of this century. The change associated with climate has never been smooth and likely to be expressed in terms of increased uncertainties and extremities of weather. Number of heat waves witnessed during last 25 years (1990–2015) in tropics has exceeded as compared to preceding 70 years. Similarly the number of extreme rainfall events as well as drought has also increased in recent past. These changes are likely to impact natural resources, societies and their interdependence.

Fruit production being one of the important activities in tropical regions has been largely ignored from the systematic impact analysis of climate change and adaptation studies. Tropical fruits are attuned to the prevailing weather conditions marked by high temperature. There are delineated and definite ranges of temperature at different phenophases for optimum production of different fruits. Any deviation from the optimum is likely to affect production and quality drastically. The complex interaction of altered temperatures, corresponding phenophases of different fruits, relative suitability of species and cultivars, elevated $CO_{2,}$ reduced water availability, pollinators, pest and disease and management practices have demonstrated impact and thus will largely determine the tropical fruit production. Tropical fruits where production is presently limited by high temperature are likely to suffer most and probably have to shift to new areas. Some tropical fruits growing in elevated/fringe

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areas and production is limited by law temperature are likely to be benefited from elevated temperature. For rest of the large section of tropical areas, a strong adaptation strategy needs to be developed. In all above three cases, preparedness which is essential part of adaptation is must to deal with extreme weather events and increased uncertainties. In general, higher resilience of tropical perennial fruits against climate change as compared to annuals needs to be properly harnessed through adaptation mechanisms.

Suitable and improved cultivars, alteration in cultural practices including plant architectural management, water management, micro climate modifications, soil organic carbon built-up etc. are possible adaptation strategy. Shifting tropical fruit cultivation to new areas as an option is still debatable but seems necessary owing to extending tropics Adaptation strategy must have imbedded some mitigation potential in long run.

Keywords Climate change · Tropical fruits · Impact and management

11.1 Introduction

The year 2016 has been declared as warmest year in the recorded history of climate data. There is almost unanimous agreement among scientist that tropics will be first and most to bore brunt of climate change even though the magnitude of projected change as well as past climate trend is moderate as compared to other part of the words. Reason are complex comprising economic, geographic and meteorological factors including relatively narrow temperature ranges means even the small deviation is likely to have significant effect (Martin 2015). Estimated changes in terrestrial metabolic rates in the tropics are large, because of warm base line temperature (Dillon et al. 2010) even though tropical temperature change has been relatively small. Carbon cycle in the tropics has becomes more sensitive to temperature change in last 50 years and around two billion tons of more carbon per year is likely to be released from tropical forests and savannahs, in response to 1 °C rise in temperature compared with the 1960s and 1970s (Ross 2013). In addition, warming has extended the tropical region over last several decades' (Lovett 2007) resulting newer areas are getting importance for tropical fruits.

Global warming is inevitably happening and affects many aspect of life on earth. More fluctuation in temperature, rainfall, occurrence of frequent drought, floods, storms are likely expressions of climate change. There are many projections for future climate and temperature projections which show an increase of up to 6 °C by the year 2100 while CO_2 concentration might increase to 850 ppm. Temperature is known to affect both photosynthesis and respiration and their ratio must be high in order to achieve high yield (Moretti et al. 2010). Photosynthetic activity increases with temperature until certain level but further increase in temperature results inactivation of enzymes thus reduces the ability to cope with heat stress. Temperatures above 35 °C are considered to stop ripening process in climacteric fruit as it suspends ethylene production. Zhang et al. (2011) reported very high response of heat stress

(43%) in terms of protein spots in a hot water treatment in peach. Higher temperatures during growing season also resulted in earlier harvest.

Developing countries account for about 98% of tropical fruit production. Tropical areas is though endowed with great diversity of tropical fruit trees, out of about 2700 species very few are commercially grown and even lesser number is traded (Paull and Duarte 2011). Presently the impact of climate change on tropical fruits has been somewhat neglected probably with assumption that these fruits are already adapted to hot and humid conditions and also due to difficulty attached in experimentation with perennial, however, there are reports of impacts, most notably on tree phenology, especially flowering and fruiting.

Fruit crops have longer period of flowering thus stay exposed to climate variability. Temperature brings about changes in hormones needed for growth and development of trees. In these fruit species temperature play important role in flower bud differentiation as well as flowering and fruit set. Symptoms like early blooming and advanced crop harvest has already been seen (Hribar and Vidrih 2014) in some crops including mango and litchi. Tropical fruit production is not only directly affected by weather modification as expression of climate change but also by the changed over all production scenario and competition for resources. Developing effective adaptation strategy along with mitigation efforts are must for sustainable and quality production in these fruit crops.

11.2 Global Climate Change Scenario

Globally the increase in greenhouse gas concentration in the atmosphere has been considered as the prime causes for climate change. Major greenhouse gases such as carbon dioxide, methane, nitrous oxide, sulpherdioxide, etc., are increasing in the atmosphere. Burning fossil fuels, deforestation, industrial processes, some agricultural practices have contributed to increased greenhouse gases into the atmosphere. After fossil fuel use, land use change and forestry, especially deforestation and degradation, are the next largest emitters of CO_2 (Baumert et al. 2009). CO_2 alone is responsible for 77% of global warming (Climate Analysis Indicators Tool 2011). The CO_2 concentration in atmosphere has sharply increased from 280 ppm (preindustrial period) to 400 ppm in 2014 (Vati and Ghatak 2015). Global air temperature increased by 0.74 °C between 1906 and 2005 (IPCC 2007a) which is further projected to increase by 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 (IPCC 2007b). The rate of sea level rise was 1.8 mm per year over 1961 to 2010 (Chadha 2015).

Global warming which is predicted by general circulation models and supported by mounting evidence will lead to an excessive change in climate conditions and thereby crop production. Global temperature is projected to increase up to 6 °C by the year 2100 while CO_2 concentration is projected to increase in the range from 550 to 850 ppm (Hribar and Vidrih 2014). Increase in temperature by the end of the twenty-first century and under the GHGs emission scenario SRES-A2 (IPCC 2000) is likely to be 1.8–6 °C for Asia (IPCC 2007) even after accounting most of the variability to the different global climate models (GCMs) used in the IPCC Fourth Assessment Report (AR4), and with warm periods showing greater increases as compared with cold periods. Though least increase is projected for South Asia (except for the Himalayas), but nevertheless it also ranges between 1.8–5 °C (IPCC 2007). Rainfall in cold season is predicted to change between −5 to 20% and for summer season between −40 to 15% (IPCC 2007). These changes will certainly affect agricultural production mainly due to over reliance of production systems on favorable climatic conditions (Jarvis et al. 2010).

Regional climate trends and projections are important for adaption strategy. For Indian condition, high-resolution climate change scenarios using regional climate models, predicted a change of 2.5 to 5.0 °C in annual mean surface temperatures over a period of 100 years across different scenarios (Rupa Kumar et al. 2006). MoEF (2004) has mentioned projected increase of 2–4 °C in maximum and minimum temperature by 2050. There is large scale uncertainties associated with monsoon rainfall projections (Mishra 2015). An increase in monsoon rainfall by 20%, in most of the Indian states and reduction in rainfall in some others over a period of 100 years are also projected (Rupa Kumar et al. 2006). Mishra (2015) reported declining trend of monsoon rainfall in India. Projections show increase in number of rainy days in north-eastern parts (by 5–10 days), and decrease in western and central parts of the country. Rainfall intensity and weather extremes are also likely to increase. Kumar et al. (2010, 2010a) comparing PRECIS downscaled base line (1961–1990) with A2a scenario for the period of (2071–2100) projected 3.96 °C increase in average annual maximum temperature in Gujarat, Maharashtra and Madhya Pradesh with highest mercury level in month of November. For North West part of the country, Kumar et al. (2010a, 2010) indicated more increase (to the tune of 5.6 °C) in average annual temperature which may affect productivity and seasonality of many crops and perennials. Using the CMIP5 climate projections, Chaturvedi et al. (2012) reported 3–4 °C increase in projected temperature under the representative concentration pathways (RCP) 8.5 by the end of twenty-first century and also found large uncertainty in precipitation projections. By using high resolution multimodal climate change projection Kumar, et al. (2013) reported that India is likely to be warmer by 1.5 °C and 3.9 °C by the end of 2050 and 2100 respectively as compared to 1970–1999.

In past Thailand has experienced country-wide significant warming over the last four decades and the extreme events associated with both the cold and warmth have changed remarkably (Limjirakan and Limsakul 2012). During 1980–2012, annual rainfall, number of rainy days, relative humidity, maximum and minimum temperatures significantly increased by 29.5 mm/year, 0.83 day/year, 0.116% /year, 0.033 and 0.035 °C/ year, respectively. In tropical part of Australia, mean annual temperature in all production regions has been increased and under projected climate change condition, winter temperature rise is likely to be more as compared to summer temperature rise.

Sea level rise as a result of the melting of ice glaciers is likely to increase floods and cyclones, sea water intrusion into fresh ground water, acceleration of coastal erosion, submergence of coastal and island horticulture crops. Due to melting of glaciers, many rivers in tropical regions are at the risk of losing perennial nature thereby effecting water availability in long run. By the end of twenty-first century, sea level is projected to be 40 cm higher than present level and associated flood is likely to affect additional 80 million coastal residents in Asian countries particularly Bangladesh and India.

Although the perennial fruit trees have number of survival mechanism to cope with stress but it comes at cost of productivity and quality. Climate change impact exceeding the buffer mechanism of perennial may be un imaginable/disastrous for grower. While determining the potential area of any crops specially horticulture/perennials, the projected climate change must be considered.

11.3 Climate Optimums for Major Tropical Fruits

Mean temperature range for optimum growth of most of tropical fruits are about 24 to 30 °C (Tables 11.1 and 11.2), however some crops like mango and litchi can tolerate more than 45 °C for short period. Mango grows at temperatures as low as 0 °C and as higher as 45 °C whereas, the ideal temperature is 24–30 °C with high humidity during the growing season. Temperatures below 10 °C and above 42 °C, affect the growth. Well distributed precipitation of 900 to 1000 mm in a year is ideal.

Litchi and Longan is suitable in warm subtropical to tropical climate but frost free condition with high summer heat, rainfall and humidity are essential. Warm humid summer and cool dry winter is considered best but temperature less than 0 °C is harmful. Rambutan grows well under optimum temperature of 22–30 °C but temperature below 10° drastically reduces the growth. Citrus though a subtropical fruits is well adapted to tropical condition, the temperature of 16–20 °C is optimum but it can grow well up to 30 °C. A very high temperature is detrimental for growth of citrus. In arid and semiarid condition, best quality citrus fruits can be grown with supplemental irrigation. At least 700 mm well-distributed rainfall is necessary for these crops. Pomelo prefers warm climate (27° to 30 °C). Good quality of Guava with higher yield is produced in areas having distinct winter season. Temperature range of 23 °C to 28 °C is optimum for guava. It grows best with an annual rainfall around 1000 mm restricted between June and September. Young plants are susceptible to drought and cold. As such guava is considered tolerant to environmental stress. For custard apple, the temperatures above 40 °C and less than 0 °C are harmful. Poor fruit set in custard apple in northern India is attributed to high temperature and dry condition. For the growth and fruiting of custard apple, an annual rainfall of 800 mm is considered adequate. High rainfall, high temperature and humidity are favorable for Mango steen. Its growth is slow if temperature is below 20 °C and above 35 °C which creates stress on Mango steen.

Aonla grow well under tropical conditions with dry summer and frost free winter. It is adaptable to a wide range of climatic conditions from sea coast to an altitude of 1800 m (Bose et al. 1999). Tamarind grows well in tropical climate with hot

Table 11.1 Optimum climatic condition and latitudinal distribution of some important tropical fruits

Fruits	Optimum temp	Optimum annual rainfall	Lat. Range (distribution)	References
Mango	24–30	900–1100 well distributed, range(900–2500)	30°N -27°S	Mukherjee (1953), Davanport (2009)
Litchi	25–35	1200–2500	28°N -27°S	Tindall (1994), Menzel et al. (1989)
Citrus	16–27	1400–1800 (well distributed: About 700 mm)	44°N -27°S	Verjeij and Coronel (1992)
Guava	23–28	About 1000 mm (from June to Sept)	26°N -30°S	Verjeij and Coronel 1992
Mangosteen	25–35	(1200–1800)	12°N -10°S	Osman and Milan (2006), Cox (1976)
Tamarind	18–25	100–1400	15°N -23°S	
Rambutan	24–32	1500–2500	18°N -17°S	Tindall (1994), UDPMS (2002), Verjeij and Coronel (1992)
Ber	22–36	700–1600	22°N -18°S	
Aonla	20–34	700–2000 (dry summer, frost free winter)	35°N -18°S	Bose et al. (1999)
Pomelo	27–30	1800–2200	35°N -35°S	Verjeij and Coronel 1992, Gaffar et al. (2008)
Jackfruit	16–28	1000–1500	28°N -30°S	Ghosh (2000), Haq (2006)

Table 11.2 Optimum temperature, precipitation and latitude condition for other fruits gaining popularity in tropical condition

Fruits.	Optimum temp (°C)	Annual Rainfall (mm)	Latitude	Climate description
Sapota	14–38	900–1500	25°N -25°S	Tropical semiarid to arid with moderate humidity.
Custard apple	18–27	800–1800	22°N-22°S	.
Papaya	18–27	800–1500	25 N- 29S	Tropical, semiarid with mild winter
Banana	20–30	500–3000	28 N- 18S	Semiarid to humid subtropical
Pomeranate	18–36	600–1200	22 N - 29S	Semiarid tropics with hot dry summer and cold winter.
Longan	20–25	1400–1600	14°N-30°S	Warm subtropical to tropical with frost free winter.

summers and dry but mild winters. It is drought resistant but susceptible to frost. Ripening of fruits do not commence under cold climate (Singh 1992).

Though the optimum climatic conditions are defined for different tropical fruits but it can sustain deviation in day to day weather variation to certain extent. However this variation of weather is likely to increase under climate change condition and therefore its impact need to be studied and adaptation must be explored.

11.4 Impact of Climate Change on Tropical Fruits

Climate change may have negative as well as some positive impacts on tropical fruits however even for full actualization of positive impact, there is need to develop suitable strategy. Warming has been core of many study regarding climate change impact, elevated CO_2 and changed precipitation are also considered important.

Change in time to harvest, reduced irrigation water, increased irrigation cost, changed suitability and availability of cultivars for current and future production, increased physiological disorders, inferior qualities, increased pest (extra generation of insect pest and more period of activities) and disease, as well as outbreak of new pests and diseases, extreme event damage, negative effect on soil due to extreme rainfall and temperature are most important factors which can be associated with impact of climate change on tropical fruits.

Phenological shifts in response to climate change have been reported from different parts of the globe, Europe- Sparks and Menzel (2000), United States - Parmesan and Yohe (2003), Australia - Chambers (2009) and East Asia - Sthapit et al. (2012).

Changes in rainfall distribution affects year-to-year variations in flowering, productivity and quality of tropical fruits (Sdoodee et al. 2010). Flowering period of tropical fruits in Thailand tends to shift to second-half of the year (Apiratikorn et al. 2014). Climate variability in southern Thailand may cause off-season flowering of longkong and change in rainfall distribution may shift flowering of longkong to the second-half of year Uraipan (2009)**.** Chen Q (2012) reported total crop failure in banana production due to extreme climate. Warmer night deteriorated the fruit quality particular fruit flavor in China. Reduced crop duration and yield due to dry spell during flower emergence & fruit sets has also been observed in banana. Increase of 1–2 °C temperature beyond 25–30 °C promotes vegetative in place of flowering flushes in citrus whereas untimely winter rain affects flower initiation and favors Psylla incidence.

Rise in a temperature of above 1 °C may shift a major area of potential tropical fruits. Many suitable areas of fruit crops may become marginally suitable where as new suitable area may come up. Increased temperature is likely to have more prominent effect on reproductive biology of these crops. Rapid development of fruit and maturity is predicted in citrus, grapes and litchis due to increased temperature. The faster maturity, quick ripening may reduce fruit availability period (Kumar 2015). Floral abortion and poor pollination due to warming is also anticipated. Soil and canopy temperature increase earlier in spring may adversely affect grafting time and callus formation. Increased irrigation requirement due to higher evaporation coupled with faster development of trees due to faster accumulation of heat unit reduces fruit sizes and anthocyanin pigmentation in litchi.

Both early and delayed flowering may be characteristic features in mango under changed climate. Low temperature (4 to 11.5 °C), high humidity (>80%) and cloudy weather in January has been observed to delay panicle emergence whereas low temperatures during inflorescence development reduces number of perfect flowers (Chadha 2015) At temperature regime of around 27/13 °C, perfect flowers were significantly higher than in a temperature regime of 21/14 °C in mango. In the regions experiencing severe winter, mango malformation is a common problem (Sankaran et al. 2008) and thus may get benefited under warmer climate. Unseasonal rain coupled with variation in temperature and high humidity may result to altered flowering trend, delayed panicle emergence and fruit set (Chadha 2015). Increased temperature during panicle development in mango may speed up the growth and reduces the number of days available for effective pollination. Desiccation of pollen and poor pollinator activities are also likely to worsen the situation. Flower bud may change into vegetative one under warm night condition. Area optimally suitable for Dussaheri, a popular mango variety drastically reduced with 1 °C increase in temperature and Alphanso (a mango cultivar) is likely to be confined to Ratnagiri area due to its suitability under changed climate (Dinesh and Reddy 2012) Increased frequency of early rain for some mango area may result in to blackening. In Southern India, even marginal increase of temperature in Nov and Dec may reduce flowering in mango. Elevated temperature is attributed for fruitlet and flower dropping in mango. Rains at flowering are harmful, washout of pollen grains during flowering and poor pollination due to reduced pollinator activities has been reported (Rajan 2012). Under continued high humidity due to unseasonal rain, severe attack of mango hoppers and certain fungi and heavy shedding of flowers and fruits take place. In case of frequent hail storms, mango cultivation is not feasible (Bhriguvanshi 2010). In mango cv. Chausa the rate of development of fruit fly increased with the increase in temperature from 20–35 °C (Kumar and Shukla 2010). Dussaheri , a popular mango variety of Uttar Pradesh produces 40–50 days early crop when grown in Andhra Pradesh. At high soil temperature, more "spongy tissue' a physiological disorder has been observed in Alphonso, a popular mango variety from Konkan region, India.

Citrus plants grow well in tropical and subtropical climates, with very high temperatures being detrimental. Warm days and cool nights are good for color development. Soil moisture stress coinciding with maturation improves TSS and reduces acidity. Cool weather in subtropics and moisture stress in tropics are known condition that favours conversion of major part of the shoots to flower at one time during the year. Increased temperature may increase water requirement in tropical condition and reduced flowering in subtropical condition where plant puts to flower under cold stress. Warming may be favorable for scale and mite pest in citrus because of drier and dustier condition. Increase in temperature beyond 30 °C promotes vegetative instead of flowering flushes.

Good quality of guava is produced in area having distinct winter season. Guava is though more tolerant to environmental stresses, young plants are susceptible to drought and cold. Red color development on the peel of guava requires cool nights during fruit maturation. Warner night temperature may impair the colour development. Varieties like Apple Color guava, which have attractive apple skin color under subtropical conditions of North India, have red spots on the skin under warmer conditions. Observation in areas suitable for production of red color guava) revealed negative correlation of total soluble solids, fruit firmness and percentage dry mass with temperature during fruit growth (Rajan 2008). However, the relationship varied with the cultivar (Hoppula and Karhu 2006). Even few daily events of extremely high temperatures (above 40 °C) which are often encountered in northern India is harmful. With projected change of 1 to 5 °C, with seasonal contrast, the area suitable is likely to reduce. Although plants can tolerate extreme climatic conditions, yet for good fruiting, high humidity, occasional rains and warm temperatures are required (Bose et al. 1999).

Aonla is adaptable to a wide range of climatic conditions (Bose et al. 1999). However in the event of frost, it is severely affected and in young budded plants scion portion and young grafts are dried. It is one of the fruit considered having greater resilience under climate change condition as it can sustain draught. Varieties that matures before occurrence of frost, produce maximum (More and Rakeshbhargava 2010).

Though high temperature in general improves fruit quality but excessive temperature has found to delay maturity in grapes. Color development has also been found to reduced due to excessive temperature. Damage due to downy mildew in grapes increased with temperature coupled with unseasonal rains. Advancement is cherry blossom by 4 days was observed in response to 1 °C rise in March temperature in Japan and Korea (Yoshino and Sook 1996). Higher temperature also results into flower drop of female and hermaphrodite plants in papaya. In banana, dry spell during flower emergence and fruit set reduces crop duration.

The predicted changes of rainfall and temperature are also likely to affect tropical fruits and regions through changes in enterprise structure and location. Increased irrigation demand and altered reliability of irrigation schemes and water availability is likely to be core issue for tropical fruit under changed climate. Redistribution of existing pests, diseases and weeds and increased threat of incursions into new crops, prominence of otherwise minor pest and disease, more physiological disorders like tip burn, sun burn, fruit cracking (Kumar and Kumar 2007), blossom end rot, hail damage and soil erosion etc. are likely impacts for which evidences are mounting. Drought and floods may promote soil borne disease. Phytophthora infection may increase in flood condition and likely to spread more. Poor color development, quick desiccation, less residence time on tree due to fast maturity are likely impact on tropical fruits. Severe pressure on food security in South Asia and Africa is predicted under climate change condition (Lobell et al. 2008).

Though impacts of climate change are likely to be adverse, but a careful adaptation strategy and preparedness for harnessing good opportunities provided by elevated CO_2 and temperature may compensate to great extent. Kimball et al. (2007)

reported that sour orange (*Citrus aurantium*) plants grown for 17 years in elevated CO_2 (300 ppm above ambient), produced 70% more fruit instead of acclimation. It also increased biomass accumulation (70% extra) due to higher wood growth. Altered carbon availability to mango fruit affected both dry mass and water mass of peel, pulp and stone (Léchaudel and Joas 2007).

Using Eco Crop data set, base line data of GCM (Had CM3) and projected data using DIVA GIS model, area suitability of some important tropical fruits was determined (Beebe et al. 2011). It shows an average increase of 1.6% in suitable area of mango globally, with 26% of the global suitable areas for mango production being negatively impacted. For coconut, some 40% of the global suitable areas seem to be decreasing their climatic suitability whereas increase of about 1% suitable area is predicted. Similarly in case of orange some (<1%) area is added to suitable area but suitability is reduced in about 46% of suitable area (Mathur et al. 2012).

11.5 Adaptation Strategy to Mitigate Ill Effects of Climate Change in Tropical Fruits

Adaptation is important but mitigation must be part of adaptation because even if we stop all emissions, the temperature will continue to rise for many decades before it gets stabilized. If left unattended, the rate of increase of will cross many dangerous tipping points which further accelerate climate change to the extent that adaptation may become inadequate (Sthapit and Scherr 2012). Mixing adaptation and mitigation is the best strategy to achieve greater levels of both adaptation and mitigation (IPCC 2007). There is sufficient scope in agriculture, land use and forestry sector, to attend adaptation and mitigation jointly as one provides opportunities for the other.

The simplest adaptation strategy to maintain tropical fruit is development and use of adaptable cultivars and cultural practices (Singh 2012). Adapting to changed climate in current location is main option at farmer's level where as shifting current production system to new favorable location is also an option and global scale. Due to perennial nature, tropical fruit trees are considered to be more resilient therefore provide important adaptive values to climate change (Chadha 2015) and can be an important substitute for more vulnerable annuals. However, if impacts exceed adaptation capacity of current location, it can be catastrophic and then northward shift of agro climatic zones in tropical region of northern hemisphere and south ward shift in southern hemisphere may be inevitable. Climate change is already considered to be shifting the habitat ranges of plants and animals (Pereira et al. 2010).

The most important adaptation and mitigation strategy in tropical production system is enrichment of soil organic carbon, as it not only has the biggest agriculture based mitigation potential but also provides resilience against climate change. Minimizing tillage, erosion and chemical use, incorporation of organic inputs and use of perennials are key strategy. Perennial tropical fruit is good substitute for annual.

11.5.1 Change of Crop and Varieties

Change in crop and variety in response to changing climate in one of the greatest adaptation strategy. Crop varieties which are able to withstand biotic and abiotic stresses offer greater climate resilience. Identifying more adaptable cultivars and a range of cultural practices may help growers maintain current production. Drought tolerant varieties and varieties that can skip stress loaded period though modified fruiting period need to be developed/ identified. Pomegrante hybrid Ruby (drought tolerant), Annona hybrid Arka Sahan (drought tolerant) and Grape root stock Dogridge (*Vitis champine*) has been found promising. Different races and genetic base need to be explored and experimented. Place of origin of fruits need to be explored for climate tolerance. For example, mono embryonic type mango may be tested for land logged climate in northern India with well-defined winter and poly embryonic type may be tested for coastal climate for adaptation under changed climate.

11.5.2 Good Management Practices for Land and Plants

Good management practices comprising different aspect of production and post-production need to be adapted to provide better resilience to tropical fruit production. Adapting improved irrigation technology targeting water for plat rather than for soil, erosion control measures, drainage facilities, retaining residue infield, reducing fallow period, canopy management for optimum light utilization in different orchards are adaptation options. Developing and practicing a monthly/biweekly calendar of practices in any tropical fruits and adjusting time of operation according to prevailing weather will be advantageous.

11.5.3 Canopy Management

Canopy management for improved leaf and fruit exposure help improve yields and fruit quality (Kumar and Nath 2013). If done properly, it minimizes resource competition and improves physiological processes of crops. It is essential in many cases including Litchi. The main aim of training in younger plants is to give desired shape to canopy and developing strong framework which also offers greater resilience against strong wind. In mature plants training and pruning aims upkeep of desired shape and maximize bearable surface area. In old plants/orchards, pruning helps maintain vigour of plant which may otherwise develop senility. It has been established that pruning stimulates shoot initiation. Rising levels of atmospheric CO_2 is likely to boost canopy development which may offers conducive microclimate, more susceptible tissue, more interception of inoculums, more opportunity for infection, more polycyclic infection and radiation shield for inoculums. If all leaves which comprises 2–5% of total biomass removed in training or/and pruning is incorporated in soil, and 50% of hard biomass is used as timber with more than 30 years of life, the pruning and training is estimated to have net mitigation effect. Schaffer and Gaye (1989) found increased in light utilization in mango by removing 25% of canopy.

11.5.4 Microclimate Modifications

There is scope of minimizing impact of extreme weather event by modifying micro climate. Water has been mostly used for microclimate modification both against heat and cold stress. Overhead irrigation, mid canopy sprinkler, shade net, reflecting materials, water channels, canopy management, etc. offers adaptation options against extreme weather. The microclimate modification may also be manipulated to reduce pest and disease.

11.5.5 Micro Site Modifications

The ideal site conditions are though defined for all tropical fruits but rarely found in actual field situation. There is wide scope of micro site modification for new plantation as well as in existing orchards. Favorable soil and filling materials including manures and nutrients are used for the same. In coarse texture soil, clay enrichment is used to improve water holding capacity. Micro site improvement has been successfully used on difficult site like gravely soil, saline or alkaline soils. Micro site modification not only improves resilience against climate change but also has mitigation effects. Drying of litchi orchards planted on shallow soil was observed near Muzaffarpur, Bihar, India due to heat and water stress during 2016, but were less on adjacent site where micro site improvement though incorporation of pond soil was done.

11.5.6 Sound Weather Forecasting System

In day to day management of production affair, farmers need to tackle extreme weather probably with higher uncertainties. Though long term larger scale and very short term at smaller scale weather forecasting system has matured and performing satisfactory but there is much to be done for taluka or district level medium term weather forecasting at which is mainly used in production management. A close to accurate forecasting is very important for adjusting field operation to minimise damage to the crops.

11.5.7 Efficient Water Management

Among the crops, maximum adoption of drip system has been in coconut, followed by banana, grape, papaya, pomegranate, mango, and sapota (Chadhga 2015). Water availability is likely to be reduced even though rain fall increased marginally as more intense rain produce more runoff. Efficient irrigation system like drip irrigation will save significant water that can be used for expanding irrigated area. More favorable soil moisture coupled with elevated CO_2 may encourage more biomass production and soil carbon enrichment.

11.5.8 Water Harvesting and Artificial Ground Water Recharge

Considering more intense rainfall, in-situ as well as ex-situ water harvesting will be inevitable to meet multi sector demand including tropical fruits which usually comes lower in priority. Surface water harvesting with suitable structure and protection against evaporation loss is an important adaptation against projected drought. Artificial ground water recharge is necessary because of over dependence on ground water. Artificial recharge usually reduces the time of evaporation thus make more water available for sector like fruit production.

11.5.9 Soil and Water Conservation Measures

Warmer climate, poor soil organic matter, poor vegetation cover under tropical condition and more intense rain under changed climate make soil highly vulnerable to erosion and degradation. Soil and water conservation measures like, leveling, bunding, terracing, trenching, and including in situ moisture conservation measures like mulching are important adaptation against, frequent drought and foods. Tropical fruits grown with suitable soil and water conservation measures offer greater resilience against climate change and also have higher mitigation potential through soil protection and soil carbon builtup.

11.5.10 Degraded and Wasteland Opportunity

Significant area in the tropics is under degraded and wastelands. About 120.72 million hectare of degraded and wastelands are in India alone (Maji et al. 2010). Out of which 16.53 million hectare is under open forest (<40% canopy cover). With proper treatment approximately 50% this area can be converted to perennial fruit belt.

Greening degraded land has added advantage as it has larger carbon sink potential due to usually very poor soil carbon base line.

11.5.11 High Density Planting (HDP)

Tropical fruits have great adaptation as well as climate change mitigation potential as it not only produce more but also accumulates biomass and soil carbon per unit area. In a well-managed high density planting of perennials, terrestrial carbon accumulation can be as high as 1.5 times as compared to normal planting in one life cycle. Selective adoption of HDP is already practice in mango, guava, banana, citrus, pineapple, pomegranate, papaya, cashew and coconut. These success experience need to be utilized for other tropical fruits like litchi, longan etc. Mango, Guava and citrus can be planted at 2.5 m × 2.5 m, 3 m × 3 m and 1.8 m × 1.8 m respectively in place of 10 m × 10 m, 6 m × 6m and 6 m × 6 m respectively. Canopy management is the key to the success but future high-density plantings have to be developed by using dwarfing rootstock, inter stocks, and scion varieties. A combination of canopy management and growth regulators is important for success of HDP.

11.5.12 Protected Cultivation

Protected cultivation using net house or poly house has advantage in terms of modified micro climate and crop is less exposed to weather extremities. Increase in CO_2 build up in the growing condition can also be beneficial in enhancing photosynthesis. Reduction in pest and disease and wild animal damage is added advantage of protected cultivation. About 40,000 hectare area is used of protected cultivation in India but mostly of annuals or for nursery in case of perennial fruits.

11.5.13 Eco Fortification in Tropical Fruit Production System Through Perennial Fruit Based Cropping Model

Crops are less affected by frost if grown under the canopy of other cops. Growing different crops under partial shade in younger orchard have multiple advantages including advantage of modified microenvironment. Intercropping of coffee and bananas, growing tuber crops in litchi and mango orchards, growing shade loving medicinal plants in full grown orchards not only improves income frpm cultivation but also encourage ecological condition by reducing soil erosion, soil heating and by adding nitrogen in case of leguminous crop. This multitier cropping system including fruits has greater resilience against climate change in tropics. More plants and residue recycling under these multi cropping system has high potential for soil carbon enrichment. Adjusting management calendar as per changed cropping system and prevailing climate is another common adaptation to climate variability at the farm level.

11.6 Conclusion

With mounting evidences of climate change there is need of preparedness to minimise adverse impact as well as to harness from the opportunities. Though the predicted warming is less for tropics as compared to higher latitude, nevertheless the impact is predicted to be worse. Tropical fruits are not only exposed to changed climate but also will be impacted by changes in other sector. Early maturity, accelerated growth, altered flowering, more insect pest, new pests and diseases, increased irrigation requirement, higher physiological disorder like fruit cracking, tip burn, poor colour development, reduced fruit size are likely impact on tropical fruits. For day to day management, grower need to tackle extreme weather and increased uncertainties. Mitigation must be part of every adaptation strategy. Improved irrigation technique, microsite and climate modification, change in crop and varieties, protected cultivations, canopy management, use of growth chemicals are adaptation options. High density planting, multitier cropping, soil and water conservation, enriching soil organic carbon are mitigation options with adaption potential in tropical fruits.

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