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Horticultural crops and climate change: A review

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ABSTRACT

If agriculture is the main stay towards the emission of greenhouse gases induced climate change, horticultural crops have a much bigger role to play in countering the negative consequences of climate change by providing a better carbon trade and carbon sink. One of the most ominous physiological responses that accrue in response to climate change is the shortened growing period, causing distinctive reduction in production of fruits and vegetables. These responses will leave negative impact on growth and development of horticultural crops due to terminal heat stress and deprived soil water availability. Interventions seeking climate-smart horticulture are, therefore, felt an unwarranted necessity integrating location-specific and knowledge-intensive premise for improving production under such challenging environment. Crop-based adaptation strategies are needed keeping in view the nature of crop, its sensitivity level and the agro-ecological region. Simultaneously, keeping an eye on carbon sink potential of different horticultural crops vis-à-vis annual field crops will further aid in developing a blue print for redressal of climate change related issues.

Key words: Carbon trade, Carbon sink, Climate change, Growing period, Horticultural crops, Physiological response

Fourth Intergovernmental Panel on Climate Change (IPCC) report aptly envisaged about the global and regional impacts of projected climate change on agriculture, water resources, natural eco-systems and food nutritional security (IPCC 2007). Every year, different regions and provinces experience one or the other kind of disasters such as drought, hailstorm, heavy rain, flood, frost, cyclone and other abiotic stresses which are explained as impact of climate change. Shifting weather patterns resulting in changing climate, has threatened agricultural productivity through high and low temperature regimes and increased rainfall variability (Malhotra and Srivastava 2014, Eduardo *et al.* 2013).Climate change and its variability are posing the major challenges influencing the performance of agriculture including annual and perennial horticulture crops. Reduction in production of fruits and vegetables is likely to be caused by short growing period, which will have negative impact on growth and development particularly due to terminal heat stress and decreased water availability. Rainfed agriculture will be primarily impacted due to rainfall variability and reduction in number of rainy days (Venkateswarlu and Shanker 2012). The issue of climate change and climate variability has thrown up greater uncertainties and risks, further imposing constraints on horticultural production systems. Climate change might result in price hike of fruits and vegetable crops. Challenges ahead are to have sustainability and competitiveness, to achieve the targeted production to meet the growing demands in the environment of declining land, water and threat of climate change, which needs climate-smart horticulture interventions which are highly location-specific and knowledge-intensive for improving production in the challenged environment (Malhotra and Srivastava 2014, Malhotra 2015).

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Impacts on horticulture crops

Impact of change in technologies like new cultivars and production system management is visible in terms of increased production and productivity, which has recorded more than eleven-fold increase to 283.2 million tonnes during 2015-16 (3rd estimates) from the level of 25 million tonnes in 1950-51 (Malhotra 2016b). Certainly, horticulture sector has moved significantly despite many challenges and shortcomings, and is in crucial phase of development needing initiatives for sustainable development. To achieve the targeted production of 310 million tonnes of horticultural crops by end of XII Plan (2012-17), vertical growth, through the use of new cultivars, efficient water and nutrient management, effective plant health management coupled with strategies for reduced post-harvest losses could be the approach, which would need appropriate innovation and investment. The enhanced horticulture production is to be achieved in the challenges and consequences of climate change such as change in seasonal pattern, excessive rain, flood, hailstorm, frost, high temperature and drought leading to extremities. Reduction in yield may occur due to shortening of growing periods, decrease in water availability and poor vernalization.

To quantify the impacts of climate change on horticultural crops, we need detailed information on physiological responses of the crops, effects on growth and development, quality and productivity. The various impacts need to be addressed in concerted and systematic manner in order to prepare the horticulture sector to face the imminent challenges of climate change. The rise in temperature would lead to higher respiration rate, alter photosynthesis rate and partitioning of photosynthates to economic parts. It could also alter the phenology, shorten the crop duration, days to flowering and fruiting, hasten fruit maturity, ripening and senescence. The sensitivity of individual crop to temperature depends on inherent tolerance and growing habits. Indeterminate crops are less sensitive to heat stress conditions due to extended flowering compared to determinate crops. The temperature rise may not be evenly distributed between day and night and between different seasons (Srinivas Rao *et al.* 2010). In tropical regions even moderate warming may lead to disproportionate declines in yield. In high latitudes, crop yields may improve as a result of a small increase in temperatures. In developing countries, which are predominantly located in lower latitudes, temperatures are already closer to or beyond thresholds and further warming would reduce rather than increase productivity. The impact of climate change is likely to differ with region and type of the crop and is described here for different crop subsector of horticulture.

Fruit crops

The extreme weather events of hot and cold wave conditions have been reported to cause considerable damage to many fruit crops. In perennial crops like mango and guava, temperature is reported to have influence on flowering. Mango has vegetative bias, and this becomes stronger with increase in temperature, thus influencing the flowering phenology. The percentage of hermaphrodite flowers was greater in late emerging panicles, which coincided with higher temperatures (Singh *et al.* 1966, Ramaswamy and Vijay Kumar 1992, Balogoun *et al.* 2016). During peak bloom period, high temperature (35ºC) accompanied by low relative humidity (49%) and long sunshine hours resulted in excessive transpiration and dehydration injury to panicles. Leaf scorching and twig dying are common symptoms of heat stroke in bearing and non-bearing mango plants. Major observed effects of climate change on mango include early or delayed flowering, multiple reproductive flushes, variations in fruit maturity, abnormal fruit set and transformation of reproductive buds into vegetative ones (Rajan *et al* 2011). For monitoring of climate change, *Biologische Bundesanstalt Bundessorttenamt und Chemische Industrie* (BBCH) scale for phonological studies in mango has been modified (Hernandez *et al* 2011, Rajan *et al* 2011). In guava, there is severe increase in pests and diseases due to hot and humid conditions. Fruit fly in guava is becoming alarming due to hot and humid conditions. The crop like peach, plum, which requires low chilling temperature also showing sign of decline in productivity (Hazarika 2013). High temperature and moisture stress also increase sunburn and cracking in apples, apricot and cherries. Increase in temperature at fruit maturity lead to fruit cracking and burning in litchi (Kumar and Kumar 2007) and premature ripening of mango. Untimely winter rains promote vegetative flushes in citrus instead of flowering flushes. Dry spell during flower emergence and fruit set affects flower initiation and aggravates incidence of pest (*Psylla*).

Many slow-growing fruit crops require heavy investment on establishment of orchards. Quick alteration/ shifting of fruit species or varieties would be difficult and painful loss-bearing exercise under the impact of climate change, which may discourage the development. Recent studies have indicated that in Shimla district at relatively higher altitude orchards have been replaced from high-chilling requiring apple cultivars of apple (Royal Delicious) to low-chilling requiring cultivars and other fruit crops like kiwi, pear, peach and plum and vegetables. In mid hills of Shimla district, trend is to shift from apple and potato cultivation totally. It is corroborated by declining trend in snowfall and apple productivity in Himachal Pradesh. The production of apple has fallen from 10.8 to 5.8 tonnes/ ha (Awasthi *et al* 2001). Since many crops with chilling requirements are tree species, moving production areas is difficult. Thus in replanting orchards and plantations over the next decade, selection of lower-chilling requiring types may be advisable. This is just an example of impending impacts of global warming and climate change.

Temperature has a big influence on the rate of fruit growth, thus use of bunch covers, which are though, to warm the fruit, increased the growth rate. Higher temperature (31-32º C), in general increase the rate of plant maturity in banana, thus shortening the bunch development period (Turner *et al* 2007). Higher air temperature (>38º C) and brighter sunshine cause sunburn damage on exposed fruits. Choking of bunches is also caused by high temperatures (above 38ºC) and drought (Stover and Simmonds 1972).

Though grape originated in temperate regions, modifications in production system, taking up two pruning and one crop, has enabled it to adapt to tropical conditions. Under climate change conditions there would be changes in availability of growing degree-days (GDD)/temperature leading to hastening of the phenological processes (Wolfe *et al*. 2005, Webb *et al.* 2007, Laxman and Srinivas Rao 2005). Under conditions of higher temperatures (42ºC) vines are not capable of utilizing radiant energy possibly because of degradation of enzymes and chlorophyll exceeds rate of photosynthesis (Kliewer 1968). In wine grapes anthocyanin development is influenced by difference between day and night temperatures with high variation (15-20 ºC) promoting colour development. Hence, under such circumstances, we would have to identify varieties and regions suitable for production of quality fruits. Excessively high temperatures for extended periods of time in grapes generally result in delayed fruit maturation and reduction in fruit quality. Varieties differ in tolerance to temperature (Kadir 2005). In general, the best temperature for shoot and root growth 28 days after temperature treatments was 20/15°C for Semillon, Cabernet Sauvignon and Cynthiana and 30/25°C for Pinot Noir and Chardonnay. It was also reported that European varieties are relatively more tolerant to high temperature than the American cultivars and they have potential of production wines in hotter areas. A linear reduction in per cent acid with increasing effective heat units was evident in Valencia and Navel orange varieties indicating the negative relationship of temperature with acid/brix ratios. Shift in varietal choice may become necessary in case of grapevines, banana, mango and other important horticultural crops (Laxman and Srinivas Rao 2005, Laxman *et al.* 2010).

In citrus severe water stress causes reduction in leaf initiation, leaf size gets reduced and leaves become leathery and thick. Root growth is adversely affected by water stress. It may lead to increased rooting depth and higher proportion of feeder roots in citrus. In grape vine, developing water stress reduced inflorescence initiation in conjunction with reduced shoot growth. Water stress reduces the growth of grape berries, but does not influence the characteristic double sigmoid growth curve. Water deficit during stage I (when cell division is occurring) will generally reduce berry size more than water deficits during stages II and III (growth cell expansion). Water deficit positively affected polyphenol accumulation in berry skin and anthocyanin biosynthesis was strongly induced by water stress and the wines obtained from water-stressed plants had high anthocyanin concentration resulting in a more intense colour (Downton 1987, Idso and Kimbell 2003). In papaya, water stress imposed by suspending irrigation for 34 days arrested plant growth, induced leaf abscission and drastically decreased photosynthetic rate. Thus, it is evident that impact of water stress is more influenced by stage of growth, water stress before flowering is essential to get flowering while stress at the growth stage of fruit is detrimental. Soil water stress in banana during vegetative stage causes poor bunch formation, lower number and small-size fingers. Any water deficit would retard plant growth and the effects may sometimes be evident only several months after the drought (Stover 1972). Water stress during flowering causes poor filling of fingers and unmarketable bunches. Water stress reduces the bunch weight and other growth parameters. Microirrigation techniques have proved boon for achieving high water use efficiency in various horticultural crops (Malhotra 2010).

In mango flooding simultaneously reduced net CO_2 assimilation and stomatal conductance after 2-3 days. However, flooding did not affect leaf water potential, shoot extension growth, or shoot dry weight, but stem radial growth and root dry weight were reduced. Mortality of flooded trees ranged from 0 to 45%. Hypertrophied lenticels were observed on trees that survived flooding but not on trees that died. The reductions in gas exchange, vegetative growth, and the variable tree mortality indicate that mango is not highly flood-tolerant but appears to possess certain adaptations to flooded soil conditions (Laxman *et al*. 2010). Bananas subjected to flooding for more than 48 h are severely stunted for further development and after 72-96 h, there are no recovery of mature shoots and often die (Stover 1972).

The studies conducted in apple show that, the productivity will continue to decline up to 1500 m msl to the tune of 40-50% due to warmer climate and lack of chilling requirement during winter and warmer summers in lower elevations resulting into shifting of apple production to higher elevation (2700 m msl). Winter snowfall affects flowering. In spring, low fluctuating temperatures during bloom results in poor fruit set while warm temperatures result in desiccation of floral parts. Mild winter temperatures followed by warmer springs advanced bud burst and exposing buds to frost damage in almond and apricot. High temperature and moisture stress increased sunburn and cracking in apples, apricot and cherries (Singh 2010).

Plantation and spices crops

Cashew requires relatively dry and mild winter (15-20°C minimum temperatre) coupled with moderate dew during night for profuse flowering. High temperature (>34.4°C) and low relative humidity of <20% during afternoon causes drying of flowers resulting in yield reduction. Paucity and poor distribution of rains, increase temperature and violent winds, have been reported by Balogoun *et al.* (2016), to reduce productivity of cashew trees due to abortion or drying of the flowers, fallen of the leaves and the immature fruits and in severe conditions it may lead to unproductiveness.

Unseasonal rains at ripening stage leads to blackening of nuts as well as rotting of apples on trees. Cashew experiences severe moisture stress from January to May, which adversely affects its flowering and fruit set. In order to harvest the rainwater and to make it available to the cashew plant during the critical period, *in situ* soil and water conservation and rainwater harvesting are very important (Rupa *et al*. 2013). Cashew, which is mostly grown under rainfed conditions, is vulnerable to climatic variability and drought conditions caused due to shifts in rainfall pattern and inter seasonal variability (Yadukumar *et al*. 2010). The temperature rise will influence the survival and distribution of pest populations. Consequently shifting equilibrium between host plants and pests. The rise in temperature will hasten nutrient mineralization in soils, decrease fertilizer use efficiency. In coconut, impact of climate change related events like consecutive droughts and cyclones adversely affected nut yields (like droughts in Tamil Nadu and Karnataka, cyclone in AP) (Laxman *et al* 2010).

The studies indicate the general warming trend is in most of the coconut growing areas. Coconut productivity increased over past fifty years except recent declining trend in Maiden Karnataka, Coimbatore of Tamil Nadu due to consecutive droughts. The production was reduced by about three lakh nuts/year for four years. Productivity loss was to the tune of about 3500 nuts/hectare/year. Apart from drought other natural calamities like cyclone etc. have impacted the crop production and productivity. For instance the decline in crop production due to1996 cyclone in Godavari district of AP was to the tune of 220 millions nuts/year in six year (Naresh Kumar *et al*. 2007). In an assessment made (Naresh Kumar and Agarwal 2016) climate change is projected to increase coconut productivity in western coastal region, Kerala, parts of Tamil Nadu, Karnataka and Maharashtra (provided current level of water and management is made available in future climates as well) and also in North-Eastern states, islands of Andaman and Nicobar and Lakshadweep while negative impacts are projected for Andhra Pradesh, Orissa, West Bengal, Gujarat and parts of Karnataka and Tamil Nadu. Climatic variations had important effects on oil palm production during different stages of the plants life cycle, viz. if evapo-transpiration is reduced, leaf opening is delayed and sexual differentiation is affected. If any of these requirements are not met, the final production will be reduced during the first and consecutive harvests. Due to La Nina impact, flood related problems in southern Malaysia had decreased the production of crude palm oil to 1.1 million metric ton (26.3%) during December 2006 (Greenall 2008, Cadena *et al* 2006). Cocoa based agroforestry systems are credited for stocking significant amounts of carbon and hence have the potential to mitigate climate change. Carbon stocks in shaded agroforestry systems with perennial crops such as coffee (*Coffea arabica* L.), rubber (*Hevea brasiliensis* (HBK) Muell.-Arg.), and cocoa may vary between 12 and 228 Mg/ha and could help to mitigate climate change (Albrecht and Kandji 2003, Montagnini and Nair 2004, Nair *et al.* 2009).

The studies revealed significant changes in weather elements and have had significant impact on the production of spices crops such as small cardamom, seed spices and black pepper (Muthusami *et al*. 2012). Indian pepper production has been declining rapidly in the past 10 years due to effect of climate change. From nearly one lakh tonne of annual production, it has come down by more than 50%. A recent study by the Agricultural Market Intelligence Centre of Kerala Agricultural University reports that area under pepper farming has come down by 24% in nine years while production has declined almost half during the period due to declining productivity and increasing production costs. Pepper in Karnataka is grown mainly in the irrigated coffee plantations and is seen to be less monsoon sensitive (Ravi 2012). Das *et al.* (2016) have reviewed in detail about the impact of climate change on medicinal and aromatic plants.

Vegetable crops

Indian climate is dominated by the monsoon, responsible for most of the region's precipitation, poses excess and limited water stress conditions. Vegetables being succulent are generally sensitive to environmental extremes and high temperature, limited and excess moisture stresses are the major causes of low yields. Soil water stress at early stages of onion crop growth caused 26% yield loss. In tomato, water stress accompanied by temperature above 28°C induced about 30-45% flower drop in different cultivars (Srinivasa Rao 1995). Chilli also suffers drought stress, leading to yield loss up to 50-60%. Most vegetables are sensitive to excess moisture stress conditions due to reduction in oxygen in the root zone. Tomato plants under flooding conditions accumulate endogenous ethylene, leading to rapid epinastic leaf response. Onion is also sensitive to flooding during bulb development with yield loss up to 30-40%. Under climate change scenario the impact of these stresses would be compounded. These stresses are the primary cause of yield losses worldwide by more than 50% plant and the response of plants to environmental stresses depends on the developmental stage and the length and severity of the stresses (Bray *et al* 2000). In tomato high temperatures can cause significant losses in productivity due to reduced fruit set, smaller size and low quality fruits. Pre-anthesis temperature stress is associated with developmental changes in the anthers, particularly irregularities in the epidermis and endothesium, lack of opening of stromium and poor pollen formation (Sato and Thomas 2002). Optimum daily mean temperature for fruit set in tomato has been reported to be 21-24°C. The pre-anthesis stage is more sensitive in tomato. Post pollination exposure to high temperature inhibits fruit set in pepper, indicating sensitivity of fertilization process (Erickson and Markhart 2002). Several connecting reasons for fruit drop has been enumerated (Hazra *et al.* 2007) such as bud drop, abnormal flower development, poor pollen development, dehiscence and viability, ovule abortion and poor viability and other reproductive abnormalities. In cucumber sex expression is affected by temperature. Low temperatures favours female flower production, which is desirable and high temperatures lead to production of more male flowers (Wien 1997). The duration of onion gets shortened due to high temperature leading to reduced yields (Daymond *et al.* 1997). Cauliflower performs well in the temperature range of 15-25°C with high humidity. Though some varieties have adapted to temperatures over 30°C, most varieties are sensitive to higher temperatures and delayed curd initiation is observed (Singh 2010). The quality of horticultural commodities is likely to be most affected by heat and water stresses. In onion temperature increase above 40°C reduced the bulb size and increase of about 3.5°C above 38ºC reduced yield (Lawande *et al.* 2010). In potato, reduction in marketable grade tuber yield to the extent of 10-20% is observed due to high temperature and frost damage reduced tuber yield by 10-50%, depending upon intensity and stage of occurrence. Plants may respond accordingly to avoid one or more stresses through morphological or biochemical mechanisms (Capiati *et al*. 2006, Malhotra 2012). Advancement in appearance of aphids by two weeks with increase in 1°C and also the reduced growing period of potato seed crop. Temperature increase beyond 20°C during winter affects cultivation of seasonal button mushroom and increased incidence of diseases. Occurrence of frost during January in Rajasthan affects cumin resulting in total crop failure. Temperature raise from 20 to 22°C will increase the incidence of pest and diseases in case of cymbidium orchid (Peet and Wolfe 2000, Reynolds *et al*. 1990).

The horticultural crops having C3 photosynthetic metabolism have shown beneficial effects indicated the increase in onion yield by 25-30% mainly due to increases in bulb size at 530 ppm CO_2 (Wurr *et al.* 1998; Wheeler 1996, Daymond *et al*. 1997). Tomato also showed 24% higher yield at 550 ppm CO_2 due to increase in number of fruits (Srinivas Rao 2010). In perennial crops like coconut studies indicate the increase in shoot height, leaf area and shoot dry matter due to elevated CO_2 to the tune of 36% over chamber control (Naresh Kumar *et al*. 2008).

In onion, warmer temperatures shorten the duration of growth leading to lower crop yields (Wheeler *et al*. 1996). Any soil warming would be advantageous for cucurbits, which are generally direct seeded and have a high heat requirement. The rise in temperature will influence survival and distribution of pest population; developing new equilibrium between alternate host crops and pests; hasten nutrient mineralization in soils; decrease fertilizer-use efficiency; and increase evapo-transpiration with reduced water-use efficiency. The net effect of climate change on horticultural crops will depend on interaction effects of rise in temperature and CO_2 concentration in atmosphere (Srinivas Rao 2010). In general, CO_2 enrichment does not appear to compensate for the detrimental effects of higher temperature on yield. Most importantly, the quality of produce of these horticultural crops is likely to be impacted severely.

Excessive rains/moisture or flooding also causes stress to the annual crops particularly vegetable crops. In case of tomato flood situation has been reported to cause accumulation of endogenous ethylene which may cause damage to the plants (Drew 1979). The severity of flooding symptoms such as wilting and death of tomato plants increases with high temperature (Kuo *et al*. 1982).

Air pollution due to sulphur dioxide, nitrogen oxide, hydro-fluoride, ozone and acid rain have been reported to cause adverse effect on vegetable production in terms of reduced growth, yield and quality. Many vegetable crops namely tomato, water melon, potato, squash, soyabean, cantaloupe, peas, carrot, beet and turnip are reported more susceptible to damage from air pollution. Ambient air pollution has been reported to decrease the yield up to more than 50 percent in *Brassica oleracea, Lactuca sativa* and *Raphanus sativus* and 5-15 percent reduction in yield of vegetable crops has been reported when daily ozone concentrations reach to > 50 ppb (Narayan 2009).

Tuber crops

There are reports that high temperature brings about marked morphological changes like etiolated growth with smaller size of compound leaves and leaflets reducing the LAI (Fleisher *et al.* 2006) in addition to reduction in tuber number and size (Wheeler *et al.* 1991, Peet and Wolfe 2000, Khan *et al*. 2003,). Cool night temperature favours induction of tuberization in potato and is inhibited even if temperature is moderately high at night (Ewing 1997, Ghosh *et al.* 2000). Gross photosynthetic rate is also reduced at high temperature (Fleisher *et al.* 2006) and drastically reduces tuber yield and biomass production (Peet and Wolfe 2000). Ghosh *et al.* (2000) reported that inhibition of tuber yield was due to limited translocation of carbohydrates from leaves to tuber, reduction of nitrate reductase activity and carbohydrate expense for dark respiration. Thus diversity of potato cultivars needs to be explored for breeding heat tolerant varieties. Global warming will directly influence the choice of crop cultivars with shift towards heat tolerant ones. The elevated CO_2 concentration has been reported to reduce chlorophyll content in leaves particularly during later growing season after tuber initiation (Bindi *et al*. 2002. Lawson *et al.* 2002). Nearly all the nutrient elements tend to decrease in tuber (Fangmeier *et al.* 2002) and reduction in citric acid cause a higher risk of discolouration after cooking (Vorne *et al*. 2002).

Though cassava and sweet potato are considered to be tolerant to drought conditions (Ravi and Mohankumar 2004, Ravi and Indira 1999), significant reduction in tuber yield as well as in starch content occurs. Mild water deficit stress is favourable for tuber growth, but under unfavourable water stress conditions both vegetative growth as well as tuber bulking ceases and become dormant. Natural disasters like flood, drought and cyclones affected about 0.9 million ha area and decreased production by 40% in last 50 years (Sivakumar 2008). The screening has resulted in identification of 5 genotypes (CE-54, CE-534, CI-260, CI-308 and CI-848) and 9 land races (129, 7, 16, TP White, Narukku-3, Ci-4, Ci-60, Ci-17, Ci-80) tolerant to drought. Although cassava may sustain vegetative growth and biomass at high temperatures (33-40 ºC) under adequate soil moisture, sucrose synthesis and export from the leaves and starch synthesis in tubers will be affected at temperatures >30 ºC. Sweet potato yields decreased when the available soil moisture decreases below 20% and the tuber initiation period is the most sensitive to due to its effect on tuber number. Water stress during tuber initiation period induces lignification of tubers and hampers tuber growth. Three sweet potato land races, VLS6, IGSP 10, IGSP 14 have been identified as drought tolerant. Sweet potato variety "Sree Bhadra" tolerant to drought conditions has been released by CTCRI (Annual Report, 2013, 2014, 2015). Drought tolerance has also been attempted in seed spices crops (Malhotra 2009, Malhotra 2016).

Addressing climate change through location-specific climate smart horticulture

Climate smart horticulture is not a single specific agricultural technology or practice that can be universally applied. It is an approach that requires site-specific assessments to identify suitable production technologies and practices to address multiple challenges faced by agriculture and food systems simultaneously and holistically (Malhotra, 2014). Climate change is global, but its nature, extent and magnitude are variable in different regions and locations. Hence, the issues of climate change and solution to the problems arising out of it requires local analysis, planning and management. There is need to analyze and understand about climate change at regional levels in relation to both annual and perennial horticultural crops, which could be managed through innovation, technology evaluation and refinement to provide effective solutions to the problems (Malhotra and Srivastava 2014).

Simulation models for impact assessment

In the event of working out adaptation and mitigation strategy, it will be appropriate to utilize modelling tools for impact analysis for various horticultural crops. Availability and development of good simulation models for horticultural crops (fruit and vegetables) is lacking in India probably with exception of potato and coconut. In tomato and onion crops, the Info Crop model has been adapted and the model is being validated for different agro-ecological regions (Naresh Kumar *et al*, 2008). Perennial nature of large-sized fruit trees and shrubs are problematic in study of direct effect of various factors of growth, development and yield in controlled environment. Innovative methods are required to develop simulation models for important horticultural crops like mango, grape, apple, orange, citrus, litchi, guava, etc., on priority. Development of crop simulation models for horticultural crops in India is now a priority area of research.

Adaptation strategies

Potential impacts of climate change depend not only on climate *per se*, but also on the system's ability to adapt to change. The potential depends on how well the crops adapt to the concomitant environmental stresses due to climate change. Depending on the vulnerability of individual crop in an agro-ecological region and the growing season, the crop based adaptation strategies need to be developed, integrating all available options to sustain the productivity. The scientists have already developed several technologies to cope with extreme events like high temperature, frost and limited and excess moisture stress conditions (Naresh Kumar *et al*. 2010, Srinivas Rao and Bhatt 1992, Laxman and Srinivas Rao 2005). These available technologies could be integrated and made use to reduce the adverse impacts of climate change and climate variability. Further emphasis need to be put on developing the crop, agro-ecological region and season-based technologies to reduce the impacts and increase the resilience of horticultural production systems to climate change (Malhotra 2015, Malhotra 2012). Resistant root stocks and varieties for various fruit crops tolerant to stresses have been identified and being used to combat climate change (Table 1).

In addition to employing modified crop management practices, the challenges posed by climate change could be tackled by developing tolerant varieties. Several institutions have evolved hybrids and varieties, which are tolerant to heat and drought stress conditions, which have potential to combat impact of climate change (Table 2).

Table 1 Resistant rootstocks and varieties of fruit crops against biotic and abiotic stresses

Crop	Root stock	Trait
Mango	13-1, Kurakkan, Nileshwar dwarf, Bappakai	Salinity tolerant
Guava	*P. molle* × *P. guajava*	Wilt resistant rootstock
	P. cujavillis	Tolerant to drought, sodic soils
	Chinese guava (*P. friedrichsthalianum*)	Dwarfing, nematode tolerant and wilt tolerant
Grape	Dogridge, 110R, SO-4	Drought, salinity tolerant
Citrus	Rangpur Lime	Drought, Phytophthora tolerant
	Cleopatra mandarin	Salinity tolerant
Sapota	Khirni	Drought tolerant
Anona	Arka Sahan	Drought tolerant
Ber	*Ziziphus nummularia*	Drought tolerant and dwarf stature
	Z. mauritiana var. Tikdi and *Z. mauritiana* var. Shukhawani	Vigorous growth
	Z. rotundifolia	Vigorous growth and drought tolerant
Fig	Ficus glomerata	Nematode and salinity tolerant
Lime	Rangpur lime and Cleopatra mandarin	Salinity tolerant
Passion fruit	*P. edulis f. flavicarpa*	*Fusarium* collar rot, nematode tolerant
	P. alata	*Fusarium* wilt tolerant
Pomegranate	*Punica granatum* (variety: Ruby)	Drought tolerant
Avocado	Duke, and its progeny, Duke 7, Barr-Duke , D9 and Thomas	*Phytophthora* root rot tolerant
	G6 selection (Mexican)	*Phytophthora* root rot fairly tolerant

Source: Singh *et al.* 2009, Singh 2010

Production system management

The emphasis should be on use of recommended production systems for improved water-use efficiency and to adapt to the hot and dry conditions. Strategies like changing sowing or planting dates in order to combat the likely increase in temperature and water stress periods during the crop-growing season should be adopted. Modifying fertilizer application to enhance nutrient availability and use of soil amendments to improve soil fertility and enhance nutrient uptake (Srivastava *et al*. 2014, Malhotra and Srivastava 2015). Providing irrigation during critical stages of the crop growth and conservation of soil moisture reserves are the most important interventions (Malhotra 2016). The crop

Table 2. Arid fruit crops varieties for arid and semi-arid ecosystem

Crops	Varieties suitable for arid and semi-arid ecosystem
Pomegranate	Ganesh, Dholka, Jalore Seedless, Mridula, Phule Arakta, Bhagawa, Ruby, Amalidana, G-137, Jyoti, Basin Seedless
Ber	Gola, Seb, Umran, Banarasi Karaka, Kaithali, Mundia, Goma Kirti, Thar Bhubharaj, Thar Sevika, Thar Bhubhraj, Narendra Ber Sel-1 & 2, ZG3, Sanaur
Bael	Kagzi, Mirzapur Seedling, Etawah, Gonda, Ayodhya, NB-5, NB-9, Pant Aparna, Pant Urvashi, Pant Shivani, Pant Sujata, CISH Bael-1 & CISH Bael-2
Aonla	Banarasi, Chakaya, Francis, NA-6, NA-7, NA-10, Kanchan, Krishna, Anand-1, Anand-2, Lakshmi-52, BSR-1, Chakaiya, BSR-1
Custard apple	Balanagar, Mammoth, Island Gem, APK (Ca) 1, Arka Sahan
Fig	Poona Fig, Dinkar, Dianna, Conadria, Excel

Source: Singh *et al.* 2009, Singh 2010

management practices like mulching with crop residues and plastic mulches help in conserving soil moisture. In some instances excessive soil moisture due to heavy rain becomes major problem and it could be overcome by growing crops on raised beds. Production of vegetables could be taken up using clear plastic rain shelters, which can reduce the direct impact on developing fruits and also reduce the field water logging during rainy season. Planting of vegetables on raised beds during rainy season will increase the yield due to improved drainage and reduced anoxic stress to the root system. Grafting of vegetables on tolerant rootstocks would provide the scion cultivars with tolerance to soil related environmental stresses such as drought, salinity, low soil temperature and flooding (Chieri *et al*. 2008). Efforts initiated by AVRDC in improving flood tolerance in tomato using eggplant rootstocks for grafting could be extended to impart water stress and temperature stress tolerance (AVRDC 1990). More heat tolerant cultivars are required under climate change conditions and these cultivars need to perform at par with the conventional varieties under non-stress conditions.

Mitigation strategies

Climate change is a reality and there is enough evidence to show that the emission of green house gasses has caused global warming and associated climate change. In addition to adapting the horticultural production systems to adverse impacts of climate change, horticulture sector can considerably contribute to the mitigation. Mitigation is referred to the process in which the emission of green house gases are either reduced or sequestered. The improved crop management practices can considerably reduce the emission of green house gasses due to reduced dependence on energy needs and intensification of perennial horticultural crops will help in sequestering carbon dioxide from the atmosphere.

Carbon sequestration potential

Mitigation measures in the agriculture and forestry sectors are generating much interest as a potential source for additional income to otherwise weak rural areas and as a means of fueling adaptation to climate change. Mitigation efforts through carbon sequestration help to reduce the adverse impacts of climate change. The information about carbon sequestration potential of fruit trees is scanty though they contribute significantly. In a study using PRO-COMAP model at IISC, Bangalore estimated the mitigation potential of farm forestry fruit orchard block planting with 75% of area proposed under *Mangifera indica*, *Tamarindus indica*, *Achras sapota*, *Artocarpus*, Neem and Guava. The carbon stock change under baseline and mitigation scenario (excluding harvested wood products) and the carbon increment per ha for various project activities for the 30-year period (2005-2035) worked out to be 47.42 t C/ha. The overall mitigation potential for farm forestry with an area of 5,381 ha is 81,750 t C. fruit orchards farm forestry is found to be most profitable at 29.92% IRR (Ravindranath *et al*. 2007, Laxman *et al*. 2010).

Technological change for mitigating affect

In a matter of fact, grape is a temperate fruit, which has been largely grown under cool climate, be it for table purposes or for wine-making. But the technological change in plant architecture and production system management has helped to produce grape in tropical situation, with highest productivity in the world. Likewise the chilling will not be enough to induce flowering in apple and high temperature in the mid hill agro-climatic conditions, may cause desiccation in pollen, shrivelling of fruits resulting in reduced yield and more failure of the crops. These are the likely impact which causes the concerns. But, there are innumerable examples to cite that, climate has been changing and the technologies have helped in mitigating the problem. Salinity and alkalinity were a great problem for successful growing of grape but identification of suitable rootstocks has made it highly productive. If we look to potato, tomato, cauliflower and cabbage, these are thermo-sensitive crops and were productive only under long day conditions in temperate climate. But development of heat tolerant cultivars and adjustment in production system management has made it possible with very high productivity, even in subtropical and mild subtropical and warmer climates (Singh *et al.* 2008, Malhotra and Srivastava 2014). These are the past experiences, which clearly brings home the point that through innovative research threat of climate change could be converted into the opportunity, but will need visualization of likely change, its impact and planning to mitigate it bad impact. Now, available tools of biotechnology could add for speedier delivery of research results.

Assumptions to be addressed

1. Studies conducted by various researchers indicate the likely impact of climate change on various horticultural crops. The quantification of impacts of variations in

temperature, excess and limited moisture conditions is the first step to prepare the horticulture sector for developing adaptation strategies under climate change scenarios. Concerted efforts are needed to study and assess the impacts on individual crops under the major agro-ecological regions and growing seasons.

2. Efforts should be intensified to develop new varieties suitable to different agro-ecological regions under changing climatic conditions. In comparison to annual crops, where the adaptation strategies can be realized relatively fast using a wide range of cultivars and species, changing planting dates or season, the planting and rearrangement of orchards requires a consideration of the more long-term aspects of climate change. Therefore, before resorting to any adaptation option, a detailed investigation on the impact of climate change on perennial crops is necessary.
3. With global warming effect, production areas for specific crops and/or timing of sowing/planting could be changed, but for many horticultural crops, market windows and infrastructure, such as availability of local packing and distribution facilities are critical components of the production system needs to be relooked. The production practices which can be adjusted to compensate climate change needs scientific validation. Climate change and CO_2 are likely to alter important interactions between horticultural plants and pollinators, insect and disease, and pests and weeds.
4. The long-time horizon of perennial crops creates situations like; favourable areas may become unfavourable during the life of a single orchard. The choice of a variety is complicated by the risk that the best variety for the current climate may be poorly suited for future climates. Thus, while adaptations such as planting new varieties and shifting to new areas may reduce impacts in the long-term, short-term losses may largely be unavoidable. The physiological and morphological differences between varieties (genotypes) enable production over a relatively large range of climates and depending upon the suitability to different growing areas the cultivars may be adopted. In situations, where there is a strong consumer preference for a select cultivar and also the suitable varieties are not available to adapt to the changing climate of a particular growing region, the option of using rootstocks for better performance of the scion cultivars could be explored.
5. There is need for quick and clear understanding of impact of climate change on horticultural crops for making sound action plan because horticulture based farming systems have high potential for sequestering carbon for mitigation of climate change. The perennial trees act as carbon sinks by sequestering the atmospheric carbon. The carbon credits could be earned under the clean development mechanism. The horticultural waste could be composted locally instead of dumping in the landfills, which can reduce the release of methane that is involved in global warming.
6. Climate-smart agriculture/horticulture advocated, should contribute for achieving the goal of sustainable agriculture. It has an integration of three dimensions of sustainable development (economic, social and environmental) for jointly addressing food security and climate challenges. Such three dimensions are sustainably increasing agricultural productivity and incomes; adapting and building resilience to climate change and reducing and/or removing greenhouse gases emissions, where possible. It requires comprehensive policies at every level, adequate institutions and proper governance to make the necessary choices. It also requires new financing to address the needs in terms of investments and research and to enable the farmers to overcome barriers to adoption of new practices including up-front costs and income foregone during the transition period.
7. An integrated approach with all available options will be most effective in sustaining the productivity under climate change conditions. To achieve this end, efforts must be initiated at national and agro-ecological region level to assess the impact of climate change on different horticultural crops and to develop combinations of adaptation options for horticulture sector as a whole in an integrated manner to tackle the impacts of climate change.

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