R-2579
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REVIEW ARTICLE Agricultural Reviews

Cascading Impacts of Change in Carbon Dioxide Concentration, Temperature and Precipitation on Horticulture Crops: A Review

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10.18805/ag.R-2579

ABSTRACT

The impacts of an increase in carbon dioxide concentration, temperature and precipitation on physiology, yield and biochemical contents of horticulture crops including its mitigation measures are evident globally. This study mainly focuses on South-East Asia and Africa. We have reviewed crop-wise published literature mainly from 2000-2021 regarding the impacts of rising carbon dioxide concentration, temperature and precipitation on horticulture. Visible phenophase changes in horticultural crops such as budburst, leaf initiation, flowering, fruiting, seedling and the overall development stages of the crops are evident from the available literature. The prevalence of many diseases like blight, mildew, abaca, black sigatoka and Pierce's disease are the results of climate change. Changes in the biochemical content of the horticulture crops such as tannins, flavonol, alcohol level, acidic content, starch, amino acids, lipids, chloroplasts, sugar, organic acids and antioxidants were observed. The recommended mitigation measures throughout the literature are delayed sowing dates, efficient seed varieties, controlled fertilizer use, soil moisture conservation and other biotechnological measures. Salinity, moisture and environmental stress-tolerant crops need to develop for better management of climate change. Breeding of short-duration and heat-tolerant varieties, vulnerability quantification and early warning disease forecasting are some of the important research areas.

Key words: Climate change, Environment degradation, Greenhouse gases, Horticultural crops, Plantation crops.

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How to cite this article: Pawar, P. and Sakhale, B. (2022). Cascading Impacts of Change in Carbon Dioxide Concentration, Temperature and Precipitation on Horticulture Crops: A Review. Agricultural Reviews. DOI: 10.18805/ag.R-2579.

Submitted: 30-06-2022 **Accepted:** 05-12-2022 **Online:** 10-12-2022

Sustainable production of fruit and vegetables is the challenge of the horticulture sector posed by uncertain climate change and environmental degradation(FAO, 2015). Total greenhouse gas (GHG) emission from anthropogenic sources was estimated to be 23% derived from Agricultural, Forestry and Other Land Use (AFOLU) from 2007 to 2016. The AFOLU activities accounted for around 13% (CO_2), 44% (CH_4) and 81% (N_2O)emissions from anthropogenic activities globally (IPCC, 2019). In 2019, the concentrations of atmospheric CO_2 were higher compared to at least the last 2 million years. Concentrations of CH_4 and N_2O were also found to be higher than in the last 0.8 million years (IPCC, 2021). Simulations by global climate models have projected an increase in average global warming between 1.5-5.8°C and a 5 to 15% increase in the mean precipitation pattern by the end of the 21st century (IPCC, 2001). Food security risks due to global warming are high to very high if the average temperature rises in the range of 2°C to 2.7°C(IPCC, 2019). The major impacts of climate change are temperature rise, frost-free seasons and growing seasons will lengthen, change in precipitation patterns, an increase in drought, heatwaves, intense and stronger hurricanes, sea-level rise (1-8 feet by 2100) and the Arctic region likely to become ice-free (IPCC, 2007; IPCC, 2013). Livestock farming and rice production directly contribute to GHG emissions and thereby fuel climate change.

Globally, the semiarid region comprises approximately 90% of the area with a 99% human population and it is mainly a low-crop productivity region (Hiwale, 2015). A rise in temperature affects pollination, flowering and harvesting dates. In Arctic habitats, some plants are blooming earlier and then flower for longer periods (Giménez-Benavides *et al.,* 2010). In the last 50 years, extreme weather events like cyclones, floods, landslides and cloud bursts may decrease the production of horticulture by 40% (Sivakumar, 2019). The yield and product quality may reduce due to heat stress and heat waves (Gruda, 2005). Carbon dioxide in the C_3 pathway of photosynthesis promotes growth and productivity and is an example of a positive effect on C_3 plants. However, it cannot compensate for the rise in temperature and reduced yield of the horticultural crops. In 2007, floods in England reported very high financial losses in the horticulture sector. Direct losses caused by crop and yield decline and some indirect losses like an increase in livestock feeding costs were reported (Posthumus *et al.,* 2009). Soil fertility may get altered due to the impacts of the microbial activity of soil. In bananas, stunting is a common symptom if it is flooded for more than 48 hours continuously; waterlogging for 72-96 hours may be irrecoverable and at this stage, the banana plant often dies (Stover, 1972). The agriculture sector was adversely affected by El Nino from 1997 to 1998, especially in Indonesia, Nordeste and Brazil (Rosenzweig *et al.,* 2001). Food security risk differs between regions (Gregory *et al.,* 2005). The horticulture sector has tremendous potential to reduce the problem of hunger to a large extent (FAO, 2015). Overall, climate change threatens the agriculture system mainly due to the prevalence of pests and insects, weeds and diseases, heat stress, extreme weather events, soil fertility and erosion. The horticulture sector plays a crucial role in enriching diets, promoting gender equality, employment generation, nutritional security and income increase.

Impacts of climate change on major horticultural crops

Fruit crops

The range and abundance of major pollinators like butterflies, bats, bees and moths are shrinking with climate change. Some of the major factors like high temperature, changing rainfall patterns and increasing CO_2 levels are responsible for the impacts on fruit crops.

Citrus (Citrus species)

The optimum level of temperature and rainfall are 16-27°C and 1400-1800 mm respectively (Nath *et al.,* 2019). Water scarcity may lead to less leaf initiation, leaf size reduction and leathery and thick leaves with unfavourable root growth. The detailed study of temperature sensitivity in the phenological stages of citrus showed that a mean temperature of 20°C is required for flowering. Fruit set development may be hampered if the temperature exceeds 38°C and 50% losses can be seen at 48°C temperature. Cool temperature leads to the breakdown of green chlorophylls and heat may result in re-greening (Mechlia and Carroll, 1989). Temperature determines the fruit growth, phenophase and growing days. Fruits attain early flowering and fruit set in warmer temperatures (Nawaz *et al.,* 2020). The water requirement changes due to the potential climate change were reported for citrus from major citrus-producing regions of the world like Asia, Africa, Australia, the Mediterranean and America. In response to increasing atmospheric CO_2, the projected decrease in future citrus irrigation requirements is by up to 37% and evapotranspiration was also projected to decrease by up to 12%. However, a negative correlation has been observed between annual rainfall changes and citrus irrigation requirements. However, the prediction showed an increase in drainage and canopy interception for the 2055s and 2090s compared to the baseline period. Many authors showed that the increase in atmospheric CO_2 influences the stomatal opening and thereby decreases evapotranspiration. Moreover, the increase in temperature with constant CO_2 concentration increases the evapotranspiration and gross irrigation requirement (Fares *et al.,* 2017). In addition to the temperature and CO_2, severe droughts, extreme weather events and flooding also influence the citriculture sector. A reduction in yield, fruit size, photosynthesis and CO_2 uptake was observed.

Mango (*Mangifera indica* L.)

The optimum level of rainfall is 900-1100 mm and the temperature is 24-30°C, temperatures above 42°C and below 10°C may affect the growth (Nath *et al.,* 2019). Flowering phenology may get influenced and hot and cold waves can cause considerable damage (Singh *et al.,* 1966). Premature ripening, flowering delay, discrepancy in fruit maturity and unusual fruit sets are the major effects of temperature rise (Rajan *et al.,* 2011). Moreover, the higher temperature leads to multiple reproductive flushes and alteration of reproductive buds into vegetative buds (Rajan *et al.,* 2013). The high temperature affects the cell wall enzyme activity, delayed ripening and changes in chemical composition (Haokip *et al.,* 2020). The suitable area for mango may shift due to an increase in the temperature of 0.7-1.0°C for Alphonso and Dashehari varieties of mango (Haokip *et al.,* 2020).

Banana (*Musa spp*)

Banana requires 20-30°C temperature and 500-3000 mm rainfall for ideal growth (Nath *et al.,* 2019). An increase in plant maturity at about 31-32°C temperature results in a shortening of the bunch development period. The sunburn damage in fruits may be seen on exposure to >38°C temperature. Soil moisture deficit and water stress lead to poor bunch formation, small-sized fingers besides low numbers, poor filling of fingers and less bunch weight (Turner *et al.,* 2007). Since 1961, the annual yield has increased by 1.37 t ha^{-1} in a changing climate that shows temporary positive effects. However, by 2050, the global yield gains would reduce by 0.59 t ha^{-1} (Varma and Bebber, 2019). The infections of Black Sigatoka increased due to the increased risk of climate change in the Caribbean and Latin America. The temperature increase has resulted in a wetter crop canopy and spore germination with growth (Bebber 2019). The maximum tolerable temperature for the growth of leaf area, leaf production and dry weight increment is 33.50 to 39.20°C for bananas (Ravi and Mustaffa, 2013).

Guava (*Psidium guajava* L.)

The optimum temperature range is 23°C to 28°C and the requirement of about 1000 mm of rainfall for guava (Nath *et al.,* 2019). The temperature increase may lead to disease and pest outbreaks and fruit fly abundance (Hazarika, 2013). The increase of 0.2°C temperature may reduce the suitable area for the development of the red colour guava (Haokip *et al.,* 2020). Even though guava is an environmental stress-tolerant species, drought and cold can cause harm to younger plants.

Grape (*Vitis vinifera* L.)

It is originally from temperate regions. Higher temperature leads to higher sugar content and less amount of tartaric acid. The rise in temperature triggers an advance in phenology and harvest dates. The increase in the alcohol level by more than 2% by volume, pH by 0.2 units and decrease in acidity level by 1 g tartrate per litre. It may be the result of a rise in atmospheric CO_2, radiation and more hang time. Some of the predictable effects showed that flowering would be advanced by 15 days until 2050 and by 30 days by the twenty-first century. Similarly, ripening will also advance by 25 and 45 days, respectively. The increased evapotranspiration led to the drier vintage due to the temperature rise, while negligible effects were observed for amino acid synthesis. In red grapes, the higher UV-B radiation intensifies colour, tannin synthesis and flavonol. However, in white grapes, it may induce off-flavours and sunburn (Leeuwen and Darriet, 2016). The temperature increase affected the physiological activities of the grapes like a decrease in net photosynthesis at >25°C and starch getting replaced by lipids in leaf chloroplasts. Further warming of >30°C may reduce the weight and berry size, including the stoppage of metabolism and sugar accumulation. At elevated CO_2 levels, 40-50% biomass may increase as total biomass and dry fruit weight. Even though the level of acid and sugar equally increased at the stage of maturity, none of the variables was found to be affected due to elevated CO_2 levels (Bindi *et al.,* 2001; Mira de Orduña, 2010). The various pests and diseases and their vectors are also affected due to climate change. Some diseases may move poleward like Pierce's disease caused by *Xylella fastidiosa*.

Pomegranate (*Punica granatum* L.)

The optimum rainfall and temperature are 600-1200 mm and 18-36°C respectively. The drought situation results in the cracking of pomegranate fruits and reduces the fruit set. The temperature increase hampers the processes like photosynthesis, alteration in sugars, flavonoid content, organic acids, firmness and antioxidant activity (Haokip *et al.,* 2020).

Litchi (*Litchi chinensis*)

The fruit cracking may be observed during drought situations. It requires cold dry winters but not less than zero degrees Celsius and warm humid summers. The optimum requirement of temperature is 25-35°C and rainfall is 1200-2500 mm (Nath *et al.,* 2019). Drought may lead to stomatal closure, reducing CO_2 assimilation, leaf expansion, fruit growth and stem extension; it also hampers the process of photosynthesis (Menzel, 2005). The high temperature causes sunburn on fruits and leaves and growth inhibition of shoots and roots. The fruit's discolouration, cracking, dropping and underdevelopment of the fruits are the result of an unfavourable climate (Kumar, 2016) (Fig 1 and 2)

Papaya (*Carica papaya* L.)

The activities like stigma and sterility activities get enhanced due to an increase in temperature which also results in the flower drop and sex change in flowers(Haokip *et al.,* 2020). The optimum range of rainfall, temperature and soil moisture are 800-1500 mm, 18-27°C and 20% respectively. The environmental stress may lead to photosynthetic carbon assimilation, water deficit and lower biomass production. In turn, growth, fruit quality and yield will be affected. Soil moisture plays a crucial role in controlling the growth and yield; the 10% soil moisture reduction may decrease the leaf dry weight, central leaflet length and several leaves; a 12% soil moisture decrease may result in a shrinking of the trunk diameter, dry matter and plant height (Mahouachi *et al.,* 2006). The high air temperature increases the leaf temperature up to 42°C and decreases the transpiration to 0.20 L m^{-2} leaf h^{-1} (Ferraz *et al.,* 2015; Campostrini *et al.,* 2018).

Apple (*Malus domestica* L)

In Western Himalayas, changes in the pattern of blossom, fruit yield and quality of apples including early flowering, have been reported. Temperate fruits like apples are very sensitive to frosts; temperatures below zero can damage the flower buds and also worsens the quality of the fruits. A shift in the range of cultivation towards the higher altitude in the apple-growing region of Himachal Pradesh, India, where the temperature trend is increasing and the precipitation decreasing over the period (Rana *et al.,* 2011).

Fig 1 and 2: Litchi fruit cracking and Litchi fruit growth retardation. Both images from Kumar, 2016.

Custard apple (*Annona reticulata* L.)

Less than zero degrees Celsius and more than 40°C temperature are harmful and may lead to a poor fruit set. The optimum range of rainfall and temperature is 800-1800 mm and 18-27 mm respectively (Nath *et al.,* 2019). The higher rain and temperature may lead to the dropping of fruits and black spots respectively (Rajatiya *et al.,* 2018).

Plantation crops

Cashew

The optimum temperature and rainfall requirement for cashew are 20-27.5°C and 600-1500 mm respectively. A temperature >34°C and less than 20% relative humidity results in the drying of flowers and yield reduction. Unseasonal rain leads to more pest attacks and diseases, a decline in pollinator insect activity, poor setting, blackening and poor quality of nuts. The nut yield was reduced by 50-65% due to unseasonal rain. The salinity level (*e.g.* Tamilnadu, India) and rising sea water level due to the tsunami in coastal areas affect the cashew crops production (Yadukumar *et al.,* 2010; Rupa *et al.,* 2013).

Coconut

The production and productivity of nuts get affected due to cyclones and droughts. However, over the last 50 years, coconut production has increased in some parts of India (Kumar and Aggarwal, 2013; Singh, 2013). The coconut is mainly a rainfed plantation and drought reduces nut yield. The deficit in soil and atmospheric water leads to reduced carbon assimilation. The reduction of net carbon assimilation rate from 7% to 47% for the dwarf genotypes and from 12% to 67 for the tall genotype was reported (Repellin *et al.,* 1994; Repellin *et al.,* 1997). The biomass at elevated CO_2 concentration varies based on the exposure level of CO_2, at 550 ppm and 700 ppm biomass increases by 8 and 25% respectively (Hebbar *et al.,* 2013).

Black pepper

Kerala Agricultural University's Agricultural Market Intelligence Centre reported a rapid decline (50%) in Indian pepper production in the past 10 years. A decline (24%) in the total area under the pepper plantation was also observed (Malhotra, 2017). High temperature impedes the fruit set and fertilisation progression(Erickson and Markhart, 2002). The black pepper requires an average of 200-300 cm rainfall and 23-32°C temperature for ideal growth. The increase in rainfall from December to January decreases productivity while rainfall from March to April increases productivity. This is a thermosensitive crop and high temperatures may inhibit fruit set, especially in the post-pollination stage (Das and Sharangi, 2018).

Vegetables

Onion (*Allium cepa* L)

In the early stages, soil water stress may reduce bulb size and about 26% yield (Lawande, 2010). Flooding may decrease the yield by up to 30-40% (Singh, 2013). An increase in atmospheric CO_2 concentration also improves the yield of the onion by 25-30% (Wurr *et al.,* 1998).

Tomato (*Solanum lycopersicum* L.)

The optimum daily mean temperature for tomato fruit set is 21-24°C (Geisenberg and Stewart, 1986). Water stress supplemented by more than 28°C temperature may result in a 30-45% flower drop (Rao, 1995). Accumulation of endogenous ethylene under flooding conditions leads to an epinastic leaf response. Low fruit quality, smaller size and reduction in fruit set may be observed due to an increase in temperature. Deficient pollen growth and irregularities in the endothecium and epidermis were reported to be associated with temperature stress (Sato *et al.,* 2002).

Hot pepper (*Capsicum annuum* L.)

A detailed study was carried out by Lee *et al.,* 2017, on *Capsicum annuum* L. under two climate change scenarios. (Table 1).

At RCP 4.5 treatments, the mean plant height was the highest of all treatments. At RCP 8.5, treatments, decreased leaf length, fruit length, fruit width, dry fruit weight and fresh fruit weight, by 40.7%, 22.3%, 62.5%, 0.8/fruit and 4.1/fruit respectively. The increase in the percentage of dry matter and number of leaves were 1.3 and 2.2 times, respectively. The maximum carbon dioxide assimilation of 17.3 μmol CO_2 m^{-1} s^{-1} at RCP 8.5 was observed while no significant difference was recorded at RCP 4.5 treatments compared to the normal climatic conditions (Table 2).

The reduction of fruit yield by 89.2% compared to the normal climatic conditions. The number of harvesting days decreased from 49 to 37 days at RCP 8.5 treatment. Various RCP climate change scenarios showed a reduction in yield and growth, while negative effects were observed for photosynthesis, morphogenesis and fruit characteristics. However, more resilience was noted in the RCP 4.5 treatment of hot pepper (Lee *et al.,* 2017) (Fig 3).

Cucumber

Sex expression of male and female flowers may get affected: low-temperature results in more female flower production and high temperature leads to more male flower production (Wien, 1997).

Table 1: Shows two climate change scenarios.

	Climate change scenarios			
Treatment	Mean air temperature	Temperature	CO_2 concentration	Precipitation
RCP 4.5	22.8°C	+3.4°C	540 μmol/mol	+17.3%
RCP 8.5	22.8°C	+6.0°C	940 μmol/mol	+20.3%

Cauliflower

High humidity with 15-25°C temperature is the ideal condition, excess temperature may delay the curd initiation. The crop duration decline was seen with increasing temperature. The curd weight had a very small negative effect on rising temperature. However, Increasing CO_2 leads to an increase in curd weight and it also affects product quality (Olesen and Grevsen, 1993; Singh, 2010).

Tuber crops

Potato

The optimum temperature for the emergence of potatoes is 22-24°C and well-drained soil with a pH of 4.8-5.8. Since it is a heat-sensitive crop, less than the optimum temperature delays the growth of the sprouts. A temperature increase beyond the optimum level results in lower sprout growth, it decreases the productivity and tuber numbers of the potatoes (Sale, 1979, Ghosh *et al.,* 2000; Rykaczewska, 2015). The occurrence of frost may be infrequent due to the warming of winter, which will result in a longer growing period and more productivity in these regions (Singh *et al.,* 2005; Singh, 2008). Leaf does not expand fully at a very high temperature, which results in comparatively less light interception. The tuber yield also gets affected drastically even at moderately high temperatures without much affecting total biomass production and photosynthesis (Peet and Wolfe, 2000). The late blight (*Phytophthora infestans*) pathogen is dependent on climatic factors for infection (Lehsten *et al.,* 2017) (Fig 4).

Soil-borne pathogens like *Synchytrium endobioticum* triggering warts and *Spongospora subterranean* results in a powdery scab are enhanced by high soil moisture and low temperature. Global warming is most likely to reduce wart infection, powdery scab infection, charcoal rot, *Sclerotium wilt* and bacterial wilt (Singh *et al.,* 2013). A rise in the CO_2 level also affects the quality of the potato, increasing the amount of dry matter and starch. The decrease in the level of nitrates and glycoalkaloids results in higher-quality tubers. However, almost all types of nutrients get reduced in the tuber under elevated CO_2 conditions (Cao and Tibbitts, 1997; Schapendonk *et al.,* 2000; Donnelly *et al.,* 2001; Fangmeier *et al.,* 2002).

Sweet potato, cassava, greater yam, elephant foot yam and taro

The yield reduction may result due to < 20% soil moisture availability in sweet potato while for cassava it was a 28-42% decrease in yield in drought-like situations (Ramanujam, 1990). Pushpalatha *et al.,* (2021) carried out a detailed study on tuber crops by using the LARS weather generator to derive future climatic conditions for 2030, 2050 and 2070. The predicted results differ for different locations. The climate projection indicates the increase in minimum (3.4°C) and maximum (3.8°C) temperature; the rainfall prediction is from -721 to 448 mm. (Table 3).

Potential diseases and pests outbreaks

Lehmann *et al.,* (2020) identify the severity of the threat insects pose as a pest and identify at least one response to

Table 2: Comparative changes in hot pepper in RCP 4.5 and RCP 8.5 at 171 days after transplanting.

Treatment	leaf length (cm/plant)	leaf width (cm/plant)	fruit width (cm/plant)	dry fruit weight (g/fruit)	fresh fruit weight (g/fruit)	Yield (%)	Dry matter (%)	No. of leaves (/plant)
RCP 4.5	1.3 ↑	3.0 ↑	6.7 ↓	0.4 ↓	2.4 ↓	21.5 ↓	0.4 ↑	1033 ↑
RCP 8.5	5.7 ↓	2.2 ↓	7.5 ↓	0.7 ↓	4.7 ↓	89.2 ↓	5.4 ↑	4263 ↑

Decrease (↓)/ Increase (↑)

Table 3: Prediction of tuber crop yield changes from 2030 to 2070.

	Tuber crops yield (%)				
	2030-2070				
	Sweet potato	Cassava	Greater yam	Taro	Elephant foot yam
RCP 4.5 (Moderate emission scenario)	-32 to 14	-13 to 12	-11 to 8	-16 to 19	-10 to 6
RCP 8.5 (High emission scenario)	-38 to 13	-17 to 8	-14 to 6	-28 to 18	-12 to 4

Table 4: Carbon sequestration potential per hector.

Horticulture crop	Carbon sequestration potential in carbon tonnes/ha (C t/ha)	
	Aboveground carbon sequestration	Belowground carbon sequestration up to 0-60 cm depth
Coconut (*Cocos nucifera*) and Jamun	60.93	79.13
Coconut and Mango (*Mangifera indica*)	56.45	82.47
Coconut and Garcinia (*Garcinia indica*)	53.02	78.69
Coconut	51.14	47.06

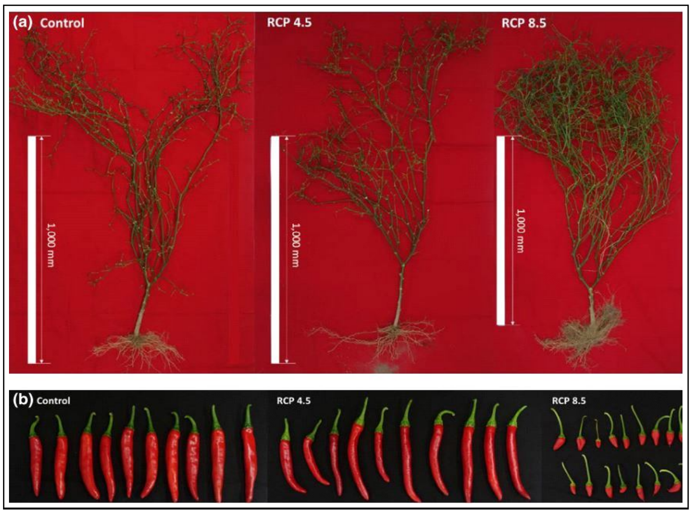

Fig 3: RCP treatments wise morphological stages of *Capsicum annuum* L. Image from Lee *et al*., (2017).

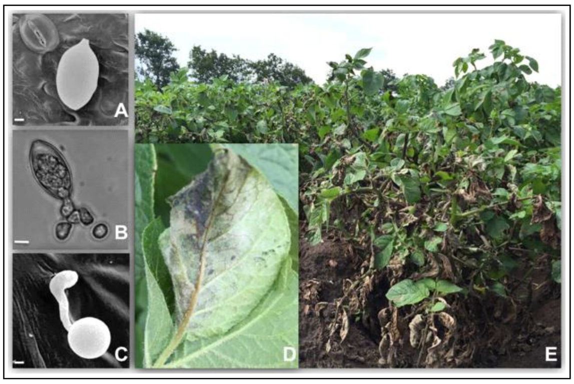

Fig 4: Late blight caused by *Phytophthora infestans*. Image from Lehsten *et al*., (2017).

warming, 41% of responses showed increased pest damage and 4% showed consistency with reduced effects. However, 55% of the insect pests exhibited mixed reactions. It shows that the severity depends on the circumstances and it may decrease or increase with ever-increasing climate change. Further research is needed to understand the complex responses of each species across the geographic range. Overall, insect pests negatively influence the productivity and profitability of forestry and agricultural operations (Lehmann *et al.,* 2020). Crop yield may improve as a slight increase may benefit the crop yield to improve from the Tropic of Cancer and Tropic of Capricorn towards the north and South poles, respectively. A slight increase in temperature in higher latitudes will aid agricultural production, however, the impact will vary based on the varieties of the crop as well as the regional climate and topography (Malhotra, 2017). Warm conditions are suitable for blight and mildew diseases in addition to pests like bugs and beetles. Overall, the different growth stages turned in favour of pests *viz*. population growth, several generations, developmental seasons, crop pests phenology and invasion by migrant pests species (Haokip *et al.,* 2020).

Carbon sequestration potential of horticulture

Horticulture can counter the adverse consequences of global warming by providing an additional carbon sink. biogas. The high-density cashew crop tremendously helps in carbon sequestration. Rubber, coffee and cocoa horticulture crops possess the significant potential for sequestration of carbon dioxide from the atmosphere. Mitigation of climate change is possible with the creation of agroforestry sinks (Albrecht and Kandji, 2003, Montagnini and Nair, 2004). In high-density plantations, it has been estimated that CO_2 sequestration of 32.25-59.22 t CO_2/ha up to seven years of crop growth is possible (Rupa *et al.,* 2013). The coconut tree can sequester up to 0.3 to 2.3 Certified Emission Reduction (CER) of CO_2 annually. However, carbon stocks may vary depending on the agro-climatic zones and the soil type (Hebbar *et al.,* 2013). Perennial horticultural crops can sequester more carbon dioxide than annual horticultural crops. In a terrestrial ecosystem, the scope of carbon sequestration is more compared to the agriculture or agroforestry system. The different crops have different carbon sequestration potentials. The decreasing order of carbon sequestration is mango, cashew, rose, vegetable, medicinal and aromatic plants. This system also helps in earning carbon credits for the horticulture system for carbon sequestration. A scientific experiment was conducted by ICAR-CPCRI, Kerala, in May-July 2015. The CO_2 sequestration was highest for the intercropping as compared to the monocrop (Bhagya and Maheswarappa, 2017; Ganeshamurthy *et al.,* 2020) (Table 4).

Mitigation measures

The potential of horticulture as a global carbon sink like the natural forest is valuable and can be exploited for the sequestration of carbon. The major adaptation approaches based on research by various scholars recommended are delaying the sowing dates, changing a variety of seeds, developing heat-tolerant and climate-resilient varieties, modification of fertilizer use, conservation of soil moisture and irrigation at the critical stages of the plants. The efficient species of horticulture crops need to develop like water succulent crops, less use of chemical fertilisers and replace with organic green manure.

The use of some of the salinity tolerant varieties of different horticulture crops like mango (Bappakai, Nileshwar dwarf, Kurakkan), Citrus (*Cleopatra mandarin*), lime (*Cleopatra mandarin*) and fig (*Ficus glomerata*). The drought-tolerant varieties such as citrus (Rangpur Lime), ber fruit (*Ziziphus rotundifolia* Lam., *Ziziphus nummularia, Z.* mauritiana var. Shukhawani and Tikdi), pomegranate (Ruby variety of *Punica granatum*) and sapota (Khirani) are important for plantations (Singh *et al.,* 2009; Singh, 2010).

For citriculture, variety breeding, rootstock breeding, change in cultivation techniques, resource optimisation and scientific knowledge have to develop. For fruit crops, the dormancy avoidance method can be employed to help in budburst without chilling temperature. It made it possible to grow temperate crops in tropical regions like India and Kenya. The artificial bud-breaking methods may help to desiccate the trees, manual defoliation, late pruning and delayed irrigation. The chilling requirement can be manipulated by planting the tree cultivars for a longer period so that it can help in adaptation. For litchi, certain mitigation measures like biotechnological interventions, breeding programmes and agro-technological advances may help to mitigate the negative impacts of climate change. To address biotic stresses, adaptation strategies like balanced nutrition, supply of plant growth regulators, bio-fertilisers, pruning and canopy management, deficit irrigation and fruit thinning may be considered for better litchi production (Kumar, 2016). For cashew crops, conservation of soil and water, mulching, proper irrigation and green manuring are the best options to tackle climate change (Rupa *et al.,* 2013). For coconut, the use of scientific technologies with drought-tolerant cultivars, soil conservation, water management and cultural practices are recommended (Hebbar *et al.,* 2013).

Grafting of the vegetable can be helpful to resist drought, flooding, salinity, environmental stresses and water use efficiency (Kubota *et al.,* 2008; Kumar *et al.,* 2017). Land degradation problems can be mitigated by using certain management options like growing green manure crops, zero tillage, crop residue retention and ground cover maintenance. In addition to that, agroforestry and horticulture can reduce soil erosion and nutrient leaching. To enhance food security, increased food productivity, agroforestry, improved cropland management, agriculture diversification, integrated water management and improved livestock management have the potential to mitigate the negative impacts of climate change (IPCC, 2019).

The evaporative cooling approach to increase the number of chilling hours may help to induce the bud burst. The use of intermittent overhead sprinklers during the hottest hours is also useful to ensure chilling and bud burst. Certain chemical treatments like hydrogen cyanamide and DNOC oil lead to earlier bud break by three to four weeks (Haokip *et al.,* 2020). Some of the mitigation strategies like land and plant management practices, canopy management, microclimate modification, microsite modification, weather forecasting system, effective water management, water harvesting, soil conservation, use of degraded and wasteland for fruit production, high-density planting and use of a net house or poly house are very effective for fruit crops (Nath *et al.,* 2019). A reduction in animal-origin food, less consumption of livestock products and policy measures are needed to mitigate the negative impacts (Friel *et al.,* 2009). The development of a healthy, diversified forest ecosystem that can tolerate more environmental stress. It may include disease control, pest management, forest fire management and limiting livestock grazing and logging will certainly result in a more resilient ecosystem. Suitable adaptation strategies should be supported through policies and institutions as well (FAO, 2015). A database of high-temperature risks associated with present and future climatic patterns is required to create. The spread of various diseases and pests under various climatic conditions and their impacts on horticulture crops are essential to document across the agroecological zones. The carbon sequestration and carbon release from horticulture crops need to quantify (Singh, 2013).

CONCLUSION

The climate change impacts on horticulture are mainly because of the changes in temperature, rainfall, weather, soil moisture, humidity, seasons, and wind pattern. Mainly the yield is the major concern of all negative impacts, while changes in phenophases, nutritional quality, growth period, fruiting and ripening are other concerns. Adaptation strategies should be the top priority for the sustainable production of horticulture. Most of the available research is based on the evaluation of crop phenophases in various climate scenarios such as flowering, pollination, the emergence of leaves, fruit development, and shoot or branch development. Different studies used various parameters like size, length, weight, diameter, height, and width have been used by the researchers to gauge the impacts of climate change on various parts of the crops. The proliferation of insect pests increased in many parts of the globe, including a shift in the range of pests. The carbon sequestration potential of the horticultural crop is tremendous, the horticulture sector can be a carbon sink like the ocean and forest sink in addition to that of the soil and atmosphere.

Conflict of interest: None.

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