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Climate Change and Horticulture Crop Production

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Abstract

Horticulture sector is the major component of agriculture and has experienced serious threat from climate change. The increase in temperature and variability in precipitation pattern has led to the development of abiotic stresses which are affecting the horticulture productivity. If climatic factors changes in a region beyond the tolerance of a species phenotypic plasticity, then distribution changes of the species may be inevitable. High temperature increase plant maturity rate, effect bud and flower development, fruit cracking, sun burn and upward shift of plants. Carbon dioxide is the prime substrate for photosynthesis and from plant perspective additional CO_2 may be beneficial, but the interaction effect of elevated CO_2 and higher temperature caused low yield of horticultural crops. Increased CO_2 can also lead to increased carbon: nitrogen ratios in the leaves of plants or in other aspects of leaf chemistry, possibly changing herbivore nutrition. The chilling requirement for flowering of many ornamental plants is being affected by the melting of ice caps in Himalayan regions. High temperature leads to flower bud drop and unmarketable spikes in tropical orchids. Defensive mechanism in plants is lowered under stress conditions making them more susceptible to insect-pests. Therefore, attention should be given on development of adaptation technologies and quantify the mitigation potential of horticultural crops. Development of new cultivars tolerant to high temperature, resistant to insect-pests and diseases, short duration and producing good yield under stress conditions and judicious water utilization technologies should be the main strategies to meet the challenges of climate change.

1. Introduction

Horticulture is the major component of agriculture and has experienced serious climate change threat. The increase in temperature and variability in precipitation pattern has lead to development of a biotic stresses viz., heat, drought and flooding which are affecting the horticulture productivity. An increase in average air temperature of between 1.4 °C, increases of 5.8 °C in atmospheric CO_2 concentration and significant changes in rainfall pattern are expected due to climate change (Houghton et al., 2001). The global atmospheric concentration of carbon dioxide has increased from a pre-industrial value of about 280 ppm to 400 ppm and is rising at the rate of 2 ppm year^{-1}. The increase in carbon dioxide levels is associated with an increase in average global temperature. According to Inter Governmental Panel on Climate Change (IPCC) Report 2007, the global mean surface temperature has increased by 0.74±0.18 °C during the last 100 years (1906–2005). The earth temperature is expected to increase by 1.1 to 6.4 °C during 2090–2099 compared to 1980–99 in different regions of the world. The change in climate is mainly caused by increasing concentration of these Green House Gases in the atmosphere. In 1980s, scientific evidences linking GHGs emission due to human activities causing global climate change, started to concern everybody. Subsequently, United Nations General Assembly in 1992 formed Intergovernmental Negotiating Committee for Framework Convention on Climate Change (UNFCCC) which finally adopted the framework for addressing climate change concerns. Climate change according to Inter Governmental Panel on Climate Change (IPCC) refers to 'a change in the state of the climate that can be identified (using statistical tests) by changes in the mean and/or the variability of its properties that persist for an extended period, typically decades or longer. However, UNFCCC, in its Article 1, defines "climate change" as "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods". The change in climate presents both adverse and beneficial impacts on crop production depending upon the agro-ecological region, crop, season, the interaction of elevated CO_2 and warming determines the extent of climate change impact on horticulture production over an agro-ecological region. Under changing climate scenario there is a huge challenge to sustain productivity of horticultural crops. In order to provide nutritional security and sustainable farm income it is essential to understand the impacts of climate change on various horticultural crops and to provide adaptive strategies and measures to minimize the adverse effects and maximize the positive influence, if any.

2. Effects of Climate Change in Distributions of Plants

If climatic factors such as precipitation and temperature change in a region beyond the tolerance of a species phenotypic plasticity, then distribution changes of the species may be inevitable (Lynch and Lande, 1993). There is already strong evidence that plant species are shifting their ranges in altitude and latitude as a response to changing regional climates (Parmeson and Yohe, 2003; Walther et al., 2002). When compared to the reported past migration rates of plant species, the rapid pace of current change has the potential to not only alter species distributions, but also render many species as unable to follow the climate to which they are adapted. The environmental conditions required by some species, such as those in alpine regions may disappear altogether. The result of these changes is likely to be a rapid increase in extinction risk (Thomas et al., 2004). Changes in the suitability of a habitat for a species drive distributional changes by not only changing the area that a species can physiologically tolerate, but how effectively it can compete with other plants within this area. Changes in community composition are therefore also an expected product of climate change.

3. Effect of Elevated Temperature on Horticultural Crops

Higher temperature 31–32 °C increase the plant maturity rate in banana, which shortens the bunch development period (Turner et al., 2007), air temperature near to 38 °C accompanied by bright sun shine cause sunburn damage on exposed fruits, high temperatures up to 39 °C and drought causes choking of bunches (Stover and Simonds, 1972). In apple growing states viz., Himachal Pradesh, climate change has decreased apple productivity which has fallen from 10.8 to 5.8 t ha^{-1} (Awasthi et al., 2001; Singh, 2003) which was attributed to climate variability. The temperature in apple growing region of Himachal Pradesh is in increasing trend, whereas, precipitation in decreasing trends (Rana et al., 2012). Winter temperature and precipitation especially in the form of snow are crucial for dormancy induction, bud break and flowering in apples (Jindal et al., 2001). Chilling requirement for apple is 1200–1500 hours depending upon the variety, below 1000 hours fruit set is affected resulting in poor yield, at least 1200 chilling hours are required proper bud and flowering for sparking delicious in Mashobra conditions of Himachal Pradesh (Jindal and Mankotia, 2004) lack of early cold in December and January adversely affect the chilling requirements (Vedwan and Robert, 2001). The chill units showed decreasing trends up to 2400 m amsl from Bajaura in Kullu at 1221 m amsl to Sharbo in Kinnaur at 2400 m amsl. The Dhundi station situated at 2700 m amsl showed increasing trend of chill unit at the rate of 25.0 CU' $year^{-1}$ which suggests that area is becoming suitable for apple cultivation in higher altitude. Rise in maximum temperature (3.4 °C) and minimum temperature (0.97 °C) during winter season in wet region of Himachal Pradesh (1500–2000 m amsl) has declined apple productivity by 40–50% due to lack of chilling during winter and warmer summer resulting in to shifting of apple production to higher elevation (2700 m amsl) (Bhardwaj et al., 2010; Chadda et al., 2009). The apple cultivation is expanding to higher altitude in Lahaul and Spiti, upward shift in apple crop in Kullu district of Himachal Pradesh has also been reported (Pratap and Pratap, 2002).

High temperature and moisture stress cause sunburn and cracking in apple, apricot and cherries, 1 °C rise in temperature shortened the period of leaf appearance to ripening in apple trees by 2 days or by 4–5 days with a 3 °C rise (Crepinsek and Kajfez, 2004), increase in temperature at maturity leads to fruit cracking and burning in litchi (Kumar and Kumar, 2007). Increase in temperature by 1 °C rise has shortened the growth period by 1–2 weeks in Grape vine cultivars (normal growth period 150–200 days and an active temperature sum requirement of 2300–3000 °C) (Crepinsek and Kajfez, 2004). Low temperature promote reproductive morphogenesis in mango, there was an increase of 18 to 100% in auxiliary buds of Haden variety when trees were transferred to 31/25 °C following 1–3 weeks at 19/13 °C (Shu and Sheen, 1987). Temperature variations caused alterations in developmental stages and ripening time in grapes, high temperature increased number of clusters $shoot^{-1}$ and decreased number of flowers $cluster^{-1}$ (Pouget, 1981) and affected the photosynthetic process, increasing leaf temperature and influenced stomatal conductance (Lloyd and Farquhar, 2008). Avocado fruits exposed to direct sunlight had higher calcium (100%), magnesium (51%) and potassium (60%) contents as compared to fruits grown under shaded conditions. Excessively high temperatures for extended periods generally resulted in delay of fruit maturation and reduction in fruit quality in grapes (Kliewer, 1971; Kliewer and Schultz, 1973).

4. Effects of Elevated CO_2 on Fruit Crops

Carbon dioxide is the prime substrate for photosynthesis and from plant perspective, additional CO_2 may be beneficial. Average shoot length of grapevine was 312.6 cm at elevated CO_2 and temperature as compared to 206.2 cm, 255.6 cm and 224.33 cm in control, elevated temperature and elevated CO_2 alone, respectively, whereas, shoot diameter decreased at elevated temperature and elevated CO_2 and temperature, equatorial diameter of berries increased at higher CO_2 concentration, soluble solid content was highest at elevated CO_2 with 14.6 °Brix, harvest date was approximately 11 days earlier at elevated CO_2 and temperature and 4 to 2 days earlier at elevated CO_2 group and elevated temperature (Son et al., 2014). Total plant organ and dry mass for Mango cultivars viz., Kensington and Tommy Atkins grown at 350 and 700 umol mol^{-1} CO_2 concentrations was higher at 700 umol mol^{-1} CO_2, whereas, leaf mineral element content was generally lower at the same concentrations, possibly due to a dilution effect from an increased growth rate (Schaffer et al., 1997).

The fruit weight of Niitaka pear was highest 543.0 g at ambient temperature and 700 $\mu l\ l^{-1}$ CO_2 (elevated CO_2 group), lowest at (394.3 g) ambient temperature+4 °C and 390 $\mu l\ l^{-1}$ CO_2 (elevated temperature group), flesh firmness at harvest and photosynthetic rate was highest at ambient temperature+4 °C and 390 $\mu l\ l^{-1}$ CO_2 (elevated temperature group). Rapid increase in fruit diameter was observed on fruits grown under ambient temperature+4 °C and 700 $\mu l\ l^{-1}$ CO_2 (elevated climate group) (Han et al., 2012). Elevated CO_2 and high temperature caused a further 12% and 35% decrease in fruit yield of strawberry (*Fragaria×ananassa* Duch. cv. Toyonoka) at low and high nitrogen, respectively (Sun et al., 2012). The fewer inflorescences and smaller umbel size during flower induction caused the reduction of fruit yield at elevated CO_2 and high temperature, nitrogen application has no beneficial effect on fruit yield. Moreover, elevated CO_2 increased the levels of dry matter content, fructose, glucose, total sugar and sweetness index dry^{-1} matter, but decreased fruit nitrogen content, total antioxidant capacity and all antioxidant compounds per dry matter in strawberry fruit. The reduction of fruit nitrogen content and antioxidant activity was mainly caused by the dilution effect of accumulated non-structural carbohydrates sourced from the increased net photosynthetic rate at elevated CO_2. Thus, the quality of strawberry fruit would increase because of the increased sweetness and the similar amount of fruit nitrogen content, antioxidant activity per fresh matter at elevated CO_2. Hence, the elevated CO_2 improved the production of strawberry (including yield and quality) at low temperature, but decreased it at high temperature. The dramatic fluctuation in strawberry yield between low and high temperature at elevated CO_2 implies that more attention should be paid to the process of flower induction under climate change, especially in fruits that require winter chilling for reproductive growth. The increased dry matter-content (DMC) of the fruits was probably due to the increased non-structural carbohydrates sourced from the increased net photosynthetic rate of strawberry at elevated CO_2 (Lieten, 1997; Chen et al., 1997). The non-structural carbohydrates including fructose (the dominant sugar), glucose and sucrose, contribute directly to the perceived sweetness of the fruit, and these sugars account for more than 990 g kg^{-1} of the total sugars in ripe strawberries (Wang and Bunce, 2004). Therefore, elevated CO_2 which increased fructose, glucose and total sugar levels relative to other taste related compounds would improve the perception of fruit sweetness. Chen et al. (1997) reported that elevated CO_2 levels greatly improved yield and fruit quality of strawberry by increasing the total fruit number $plant^{-1}$, average fruit fresh weight, dry matter content, fruit total sugars and sugar: acid ratio.

5. Effects of Elevated Temperature on Vegetable Crops

Vegetable crops are highly sensitive to the direct effect of rise in temperature and precipitation, high temperature affect photosynthesis, respiration, aqueous relations and membrane stability, levels of plant hormones, primary and secondary metabolites and seed germination (Bewley, 1997; Bindi et al., 2001), above a certain temperature threshold, many enzymes lose their function, potentially changing plant tissue tolerance to heat stresses (Bray, 2002; Bieto and Talon, 1996). Temperature above 30 °C suppresses many of the parameters of normal tomato fruit ripening including color development, softening, respiration rate and ethylene production (Buescher, 1979; Hicks et al., 1983) and cause heat injuries (Mohammed et al., 1996).

Most of the physiological processes go on normally in temperature ranging from 0 °C to 40 °C. However, cardinal temperatures for the development of fruit and vegetable crops are much narrower and depending on the species and ecological origin, it can be pushed towards 0 °C for temperate species e.g. carrots and lettuce or 40 °C in species from tropical regions e.g. many cucurbits and cactus species (Went, 1953). In tomato, high temperatures can significantly reduce productivity due to reduced fruit set, smaller size and lower quality fruits. Lettuce, celery, cauliflower etc. grown under higher temperature matured earlier than the same crops grown under lower temperatures (Wurr et al., 1996).

High temperature causes bud drops, abnormal flower development, poor pollen production, dehiscence and viability, ovule abortion and poor viability, reduced carbohydrates availability and other reproductive abnormalities in tomato (Hazra et al., 2007) and bell pepper (Erickson and Markhart, 2002). Yield of vegetables was reduced by 5–15% when daily ozone concentration was greater than 50 ppb (Narayan, 2009). In Kullu Valley of Himachal Pradesh, the average maximum temperature for the month of May, April and August rose by 1.58 °C, 2.03 °C and 2.165 °C, respectively from 1981 to 2004 which resulted up to 40% reduction in seed production of cabbage (var. Golden Acre) (Kumar et al., 2009).

6. Effect of Elevated CO_2 on Vegetable Crops

Increased concentration of atmospheric carbon dioxide stimulates crop growth by the carbon fertilization effect (Rogers and Dahlman, 1993). Doubling of atmospheric CO_2 concentration can increase marketable yield by 30–40% in C_3 plants (Kimball, 1983; Poorter, 1993). At enhanced CO_2 plants exhibit increased rates of net photosynthesis due to increased availability of CO_2 at the chloroplast and reduced photorespiration due to increased O_2 to CO_2 ratio (Farquhar and Sharkey, 1982; Pearcy et al., 1987). The higher photosynthesis rates are manifested in higher leaf area, dry matter production and yield for many crops (Kimball, 1983; Acock and Allen, 1985). Increased atmospheric CO_2 alters net photosynthesis, biomass production, sugars and organic acids contents, stomata conductance, firmness, seed yield, light, water, and nutrient use efficiency and plant water potential (Bazzaz, 1990; Cure and Acock, 1986). Increase in atmospheric CO_2 (50% higher) increased 63% potato tuber malformation, resulting in poor processing quality and lower tuber greening (12%) whereas proteins, potassium and calcium levels were reduced in tubers exposed to high CO_2 concentrations indicating loss of nutritional and sensory quality (Hogy and Fangmeier, 2009). Elevated CO_2 can directly stimulate plant growth, affect plant resource allocation patterns and change plant tissue quality and decline. A classical experiment of Kimball showed increase of 10–143% in several C_3 crops in response to doubling of the ambient CO_2 The influence of elevated CO_2 among certain C_3, C_4 and crassulacean acid metabolism (CAM) species suggests that most of the C_3 plants showed a significant positive response to photosynthetic acclimation, *Sorghum* and *Panicum* (C_4 plants) exhibited negative response, whereas ananas, agave and kalanchoe (CAM plants) showed positive response to increased CO_2 concentration during growth. Controlled environment studies indicated that elevated CO_2 at 550 ppm improved the bulb size and yield of onion. Tomato plants grown at 550 ppm CO_2 environment produced 24% more fruits. Elevated CO_2 is reported not only to improve the yield but also alters the quality of the produce. The quality (carotene, starch and glucose content) and tuber yield of sweet potatoes increased in elevated CO_2 conditions. Increased CO_2 can also lead to increased Carbon: Nitrogen ratios in the leaves of plants or in other aspects of leaf chemistry, possibly changing herbivore nutrition (Coley et al., 1998).

7. Effects of Climate Change on Floriculture

The chilling requirement for flowering of many ornamental plants viz., *Rhododendron*, *Orchid*, *Tulip*, *Alstromerea*, *Magnolia*, *Saussurea*, *Impatiens*, *Narcissus* etc. is being affected by the melting of ice cap in the Himalayan regions. Plant species requiring high humidity and water have low survival rates. Floriculture in Indian plains is also suffering from drought, excessive rains, floods and seasonal variations. Commercial production of flowers grown under open field conditions will be severely affected leading to poor flowering, improper floral development and colour. For plants like chrysanthemum which is a short day plant, flowering round the year in open field conditions is not possible. Low temperature shut down flowering in Jasmine (<19 °C) and lead to reduction in flower size. In *Jasminum sombac* day time temperature of 27–32 °C and night time temperature of 21–27 °C are ideal. If night temperature falls below 19 °C, flower production and size are reduced. In carnation whenever night temperature is less than 13 °C the deterioration of flower quality due to calyx splitting occurs. Optimum temperature range of 13.3 to 23.8 °C has been reported for producing quality flower with least calyx splitting (Sharma and Roy, 2010). Flowers do not open up fully in tropical orchids wherever, temperatures below 15 °C. High temperature leads to flower bud drop and unmarketable spikes in tropical orchids when temperature remains 35 °C.

8. Effects of Temperature and Other Variables on Insect-pests of Fruit Crops

Increase in temperature may alter the physiology of the host and its resistance mechanism which is supposed to be temperature sensitive. Defensive mechanism in plants is lowered under stress conditions making them more susceptible. Apple orchards of Himachal Pradesh, India earlier were found to be relatively free from the attack of phytophagous mite though some infestation of European red mite, *Panonychus ulmi* was recorded in a private apple orchard of Kullu district during 1992 which later on spread to Shimla, Mandi and Kullu districts and became a regular pest. There was an outbreak of two spotted mite, *Tetranychus urticae* Koch in Shimla, Mandi and Kullu districts during 2002 (Kakar, 2003). There was a total 68.9−72.00 mm rainfall during 2002, which caused profuse egg laying (40–50 eggs $leaf^{-1}$), 20–30 mites $leaf^{-1}$ against 200.00–241.0 mm rainfall in July 2001 when egg laying was less and reported that multiplication of *T. urticae* was more under dry spell. Peak woolly apple aphid, *Eriosoma lanigerum* activity was reported during autumn months in Himachal Pradesh due to favourable environmental conditions (Thakur et al., 1992). Bhardwaj et al. (1995) found significant check in nymphal movement of woolly apple aphid, *E. lanigerum* by the rainfall even in most favourable temperature range (13.2–25.9 °C). Sood and Gupta (2005) reported that woolly apple aphid, *E. lanigerum* get its peak population during May−June, 1997 whereas during 1998 the population was higher in July, 1998. A comparison of aphid populations in both years indicated that it remained in dynamic state of fluctuation with a clear cut peak population during summer, followed by decline in rainy or late rainy season. During 1997–2003 adults emergence of apple root borer, *Dorysthenes hugelii* started emerging with the onset of pre monsoon showers during second fortnight of June (Sharma and Khajuria, 2005). During 1999 and 2000 few adults were trapped during May last week following heavy showers of rain when there was unusual rise in temperature in March−April, which caused early emergence of adults. The number of adult emergence was directly influence by the amount of rainfall during second fortnight of June to first fortnight of July.

9. Effect of Temperature and other Variables on Insect-pests of Vegetable Crops

Global warming may be responsible for the decline in abundance of *P. xylostella, H. armigera* and *Trichoplusia ni* in some regions. American leaf miner, *Liriomyza* may spread to new areas northwards with increase in temperature. Diamond back moth, *Plutella xylostella* (L) was known to colonize the Norwegian islands of Aeticocean, 800 km north of its earlier distribution range. This shift was assumed to be the result of mass movements of warm air towards higher latitudes (Coulson et al., 2002). Under Indian conditions, diamond back moth, *P. xylostella*, a major pest on cruciferous vegetables may increase up to 28–35 °C range and thereafter in areas where temperature increases further, the incidence may decrease. Similarly, leaf miner (*Liriomyza*) incidence will increases upto 30–35 °C (Sridhar et al., 2008). Devi et al. (1996) reported that maximum activity of *H. armigera* occurred at maximum temperature range of 25.9–28.1 °C in mid hill zone of Himachal Pradesh. Gupta and Raj, (2002) obtained the *H. armigera* on 12 standard weeks of 1998 in light trap during which maximum and minimum temperature was 21.1 and 9.5 °C, respectively and average relative humidity was 52%. During 1999 moth resumed activity by 10 standard weeks and continued fluctuating till the third week of June and respective maximum and minimum temperature of 21.0 and 11.4 °C and relative humidity 49%. Sharma et al. (2002) reported that regional environmental fluctuations have profuse influence on the build up of diamond back moth, *P. xylostella* and reported that increased sunshine or bright hours and nil total rainfall have resulted in high population of diamond back moth. Verma et al. (2008) reported that cabbage aphid, *B. brassicae* remained and built up its population throughout the cropping period of cabbage crop at maximum temperature range of 15.21 to 24.28 and minimum temperature range of 1.28 to 6.0 °C during the cropping period of 2004–2005 and maximum temperate range of 18.51 to 25.79 °C and minimum temperature range of 0.87 to 7.34 during 2005–06. They also reported that 24.00 mm total rainfall coupled with 69.57% relative humidity have resulted in drastic reduction in aphid population (0.80 aphid plant^{-1}).

10. Effect of elevated CO_2 on Insect Pests of Horticultural Crops

The increased level of CO_2 concentration in the environment will lead to more biomass production in the plants by way of increased plant size and canopy density with high nutritional quality foliage, giving rise to more conducive microclimate for the development of pests. Proliferation of insect species has been shown to be strongly correlated with plant biomass and height as longer plants have greater structural complexity and resources which can easily be utilized by the herbivores (Kumar, 2008). Increase in C:N ratio tends to have a detrimental effect on polyphagous insects leading to increase in carbon based allelochemicals. Further, the negative response of insects to elevated CO_2 is that they accumulate more carbon, with an increase of C:N ratio, so that insects are faced with nutritionally deficient host plants resulting in a N-dilution effect (Ananthakrishnan, 2007). Thus under higher CO_2 conditions feeding by herbivores is expected to be high to derive more amino acids. Moreover, at elevated CO_2 there is greater partitioning of assimilation of roots in crops such as carrot, radish and sugar beet. Due to increased carbon storage in roots, losses from soil borne pests may diminish under climate change (Coakley et al., 1999). Physiological and biochemical changes induced in host crop plants by rising CO_2 may affect feeding patterns of insect-pests. Pest generation times may be reduced, enabling more rapid population increases to occur pole-ward migration may be accelerated during the crop season (Sridhar et al., 2008). The elevated CO_2 increased relative consumption rate, total consumption and developmental time but decreased relative growth rate, conversion efficiency and papal weights (Stiling and Corneliessen, 2007; Robinson et al., 2012; Srinivasa et al., 2012).

11. Effects of CO_2 on Insect-pests of Vegetable Crops

Early research in California on lima bean demonstrated enhanced photosynthesis in higher concentration of carbon dioxide, a cabbage looper, *Trichoplusia ni* also consumed about 20% more leaf area (Trumble and Butler, 2009). Reduction in host quality as a result of increased CO_2 resulted in increased larval consumption rates so as to obtain adequate dietary nitrogen in generalist feeders (Lincoln et al., 1984; Coviella and Trumble, 1999; Hunter, 2001). The leaf area (%) of plants consumed by *T. ni* was not affected by carbon dioxide concentration suggesting that increased plant growth resulting from raised atmospheric carbon dioxide may benefit the plant proportionately more than the insect (Osbrink et al., 1987). Rao et al. (2009) conducted feeding trials on *Achoea janata* and *Spodoptera litura* using foliage of castor plants grown under four concentrations of CO_2, viz., 700 ppm, 550 ppm and 350 ppm in open top chamber (OTC), and ambient CO_2 in the open. Biochemical analysis of the foliage revealed that plants grown under the elevated CO_2 levels had lower N-content, and higher C-content, C:N ratio and polyphenols. Compared to the larvae fed on the ambient CO_2 foliage, the larvae fed on 700 ppm and 550 ppm CO_2 foliage exhibited higher consumption. The 700 ppm and 550 ppm CO_2 foliage was more digestible with higher values of approximate digestibility. The relative consumption rate of larvae increased, whereas the efficiency parameters, viz., efficiency of conversion of ingested food (ECI), efficiency of conversion of digested food (ECD) and relative growth rate (RGR) decreased in the case of larvae grown on 700 ppm and 550 ppm CO_2 foliage. The consumption and weight gain of the larvae were negatively and significantly influenced by the leaf nitrogen, which was found to be the most important factor affecting consumption and growth of larvae.

12. Conclusion

Climate change is bound to impact horticultural crops at any stage of crop growth and development which may influence the quality and yield. Therefore, attention should be given on development of adaptation technologies and quantify the mitigation potential of horticultural crops. Development of new cultivars tolerant to high temperature, resistant to insect-pests and diseases, short duration and producing good yield under stress conditions and judicious water utilization technologies should be the main strategies to meet the challenges of climate change.

13. References

Acock, B., Allen, A.H., 1985. Crop responses to elevated carbon dioxide concentrations. In: Strain, B.R., Cure, J.D. (Eds.). DOE Direct effects of increasing carbon dioxide on vegetation, U.S., Department of energy, Washington DC, 53–97.

Ananthakrishnan, T.N., 2007. Insects and Climate. Entomology Academy of India Base 1, 27.

Awasthi, R.P., Verma, H.S., Sharma, R.D., Bhardwaj, S.P., Bhardwaj, S.V., 2001. Causes of low productivity in apple orchards and suggested remedial measures. In: Jindal, K.K., Gautam, D.R. (Eds.). Productivity of Temperate Fruits, Dr. Y.S. Parmar University of Horticulture and Forestry, Nauni, Solan, 1–8.

Bazzaz, F.A., 1990. The response of natural ecosystems to the rising global CO_2 levels. Annual Review of Ecology and Systematics 21, 167–196.

Bewley, J.D., 1997. Seed germination and dormancy. The Plant Cell 9(7), 1055–1066.

Bhardwaj, S., Chander, R., Bhardwaj, S.P., 1995. Movement of woolly apple aphid (*Eriosoma lanigerum*) (Homoptera: Pemphigidae) on apple (*Malus pumila*) plant in relation to weather parameters. Indian Journal of Agricultural Science 65, 217–222.

Bhardwaj, S.K., Verma, K.S., Sharma, S.D., 2010. Horticulture production in North-western Himalayan region under changing climatic scenario: a case study. In: 2nd International Conference on Environmental Management, Hyderabad, India, 206–213.

Bieto, J.A., Talon, M., 1996. Fisiologiay bioquimica vegetalogy. Madrid: Interamericana, McGraw-Hill 581.

Bindi, M., Fibbi, L., Miglietta, F., 2001. Free air CO_2 enrichment (FACE) of grapevine (*Vitis vinifera* L.): II. Growth and quality of grape and wine in response to elevated CO_2 concentrations. European Journal of Agronomy 14, 145–155.

Bray, E.A., 2002. Abscisic acid regulation of gene expression during water-deficit stress in the era of the Arabidopsis genome. Plant cell and Environment 25, 153–161.

Buescher, R.W., 1979. Influence of high temperature on physiological and compositional characteristics of tomato fruits. Lebensmittel-Wissenenshaft Technology 12,162–164.

Chadda, K.L., Sharma, N.K., 2009. Climate change impacts on production of horticulture crops. In: Dhillon, W.S., Aulakh, P.S. (Eds.). Impact of climate change on fruit crops. Marendra Publishing House, Delhi, 3–9.

Chen, K., Hu, G.Q., Lenz, F., 1997. Effect of CO_2 concentration on strawberry. IV. Carbohydrate production and accumulation. Journal of Applied Botany-Angew Bot 71, 183–188.

Chen, K., Hu, G.Q., Lenz, F., 1997. Effects of CO_2 concentration on strawberry. VI. Fruit yield and quality. Journal of Applied Botany-Angewandte Botanik 71, 195–200.

Coakley, S.M., Scherm, H., Chakraborty, S., 1999. Climate change and plant disease management. Annual Review of Phytopathology 37, 399–426.

Coley, P.D., Markham, A., 1998. Possible effects of climate change on plant/herbivore interactions in moist tropical forests. Climatology 4, 43–54.

Coulson, S.J., Hadkinson, I.D., Webb, N.R., Mikkola, K., Harrison, J.A., Pedgley, D.E., 2002. Aerial colonization of high Arctic Islands by invertebrates: the diamond back, *Plutella xylostella* (Lepidoptera: Yponomeutidae) as a potential indicator species. Diversity and Distribution 8, 327–34.

Coviella, C., Trumble, J., 1999. Effects of elevated atmospheric carbon dioxide on insect-plant interaction .Conservation Biology 13, 700–12.

Crepinsek, Z., Kajfez, B.L., 2004. Effect of air temperature increase on changes in temperature sums and length of growing season. Zbornik referatv I Slovenskega sadjarskega Kongresa Z mednarodnoudelezbo, Krsko, Slovenia, 24–25 marec De 2, 785–793.

Cure, J.D., Acock, B., 1986. Crop responses to carbon dioxide doubling: A literature survey. Agricultural Forest and Meteorology 38(1/3), 127–145.

Devi, N., Raj, D., Kashyap, N.P., 1996. Monitoring of *Helicoverpa armigera* in the mid hill zone of Himachal Pradesh. Journal of Insect Science 9(2), 95–97.

Erickson, A.N., Markhart, A.H., 2002. Flower developmental stages and organ sensitivity of bell pepper (*Capsicum annuum* L.) to elevated temperature. Pant Cell and Environment 25, 123–130.

Farquhar, G.D., Sharkey, T.D., 1982. Stomatal conductance and photosynthesis. Annual Review of Plant Physiology 33, 17–45.

Gupta, R.K., Raj, D., 2002. Monitoring of *Helicoverpa armigera* (Hubher) through light and pheromone traps and relationship of catch data with abiotic factors and larval infestation on chickpea in Himachal Pradesh. Pest Management and Economic Zoology 10(2), 103–110.

Han, J.H., Cho, J.G., Son, C., Kim, S.H., Lee, In Bog choi, In myung, Kim, D., 2012. Effect of elevated carbon dioxide and temperature on photosynthesis at fruit characteristics of Niitaka pear pear (*Pyrus pyrifolia* Nakai). Horticulture Environment and Biotechnology 53(5), 357–361.

Hazra, P., Samsul, H.A., Sikder, D., Peter, K.V., 2007. Breeding tomato (*Lycopersicon esculentum* Mill.) resistant to high temperature stress. International Journal of Plant Breeding 1(1), 31–40.

Hicks, J.R., Manzano, M.J., Masters, J.F., 1983. Temperature extremes and tomato ripening. In: Proceedings of fourth tomato quality workshop 4, 38–51.

Hogy, P., Fangmeier, A., 2009. Atmospheric CO_2 enrichment affects potatoes: to tuber quality traits. European Journal of Agronomy 30, 85–94.

Houghton, J., Ding, Y., Griggs, D., Noguer, M., Vander Linden, P., 2001. Climate Change 2001: The Scientific Basis. Published for the Intergovernmental Panel on climate Change. Cambridge University Press, Cambridge, UK and New York 881.

Jindal, K.K., Chauhan, P.S., Mankotia, M.S., 2001. Apple productivity in relation to environmental components. In: Jindal, K.K., Gautam, D.R. (Eds.). Productivity of Temperate Fruits, Dr. YS Parmar University of Horticulture and Forestry, Nauni, Solan, 12–20.

Jindal, K.K., Mankotia, M.S., 2004. Impact of changing climatic conditions on chilling units, physiological attributes and productivity of apple in western Himalayas. Acta Horticulture 662, 111–117.

Kakar, K.L., 2003. An outbreak of two spotted mite *Tetranychus urticae* Koch in Apple orchards in Himachal Pradesh. Acta Horticulture 2(696), 411–413.

Kimball, B.A., 1983. Carbon dioxide and agricultural yield: as assemblage and analysis of 430 prior observations. Agronomy Journal 75, 779–88.

Kliewer, W.M., 1971. Effect of day temperature and light intensity on concentrations of magic and tartaric acids in *Vitis vinifera* L. grapes. Journal of American Society of Horticulture Science 96, 372.

Kliewer, W.M., Shultz, H.B., 1973. Effect of sprinkler cooling of grapevines on fruit growth and composition. American Journal of Enology and Viticulture 24, 17.

Kumar, P.R., Yadav, S.K., Sharma, S.R., Lal, S.K., Jha, D.N., 2009. Impact of climate change on seed production of cabbage in North Western Himalayas. World Journal of Agricultural Sciences 5(1), 18–26.

Kumar, R., Kumar, K.K., 2007. Managing physiological disorders in litchi. Indian Horticulture 52(1), 22–24.

Lieten, F., 1997. Effect of CO_2 enrichment on greenhouse grown strawberry. Acta Horticulture 439, 583–586.

Lincoln, D.E., Sionet, N., Strain, B.R., 1984. Growth and feeding response of *Pseudoplusia includes* (Lepidoptera: Noctuidae) to host plants grown in controlled carbon dioxide atmosphere. Environmental Entomology 13, 1527–30.

Lynch, M., Lande, R., 1993. Evolution and extinction in response to environmental change. In: Huey, R.B., Kareiva, P.M., Kingsolver, J.G. (Eds.). Biotic Interactions and Global Change. Mass: Sinauer Associates, Sunder land 234–250.

Mohammed, M., Lloyd, J., Farquhar, G.D., 2008. Effects of rising temperatures and CO_2 on the physiology of tropical forest trees. Philosophical Transactions of the Royal Society of Biological Sciences 363, 1811–1817.

Narayan, R., 2009. Air pollution-A threat in vegetable production. In: Sulladmath, U.V., Swamy, K.R.M. (Eds.). Horticulture and Livelihood Security and Economic Growth. International Conference on Horticulture (ICH-2009), 158–159.

Osbrink, W.L.A., Trumble, J.T., Wagner, R.E., 1987. Host suitability of *Phaseoluslunata* for *Trichoplusiani* (Lepidoptera : Noctuidae) in controlled carbon dioxide atmospheres. Environmental Biology 16, 639–44.

Parmesan, C., Yohe, G., 2003. A globally coherent fingerprint of climate change impacts across natural systems. Nature 421(6918), 37–42.

Pearcy, R.W., Bjorkman, O., Caldwell, M.M., Keely, J.E., Monson, R.K., Strain, B.R., 1987. Carbon gain by plants in natural environments. Bio Science 37, 21–29.

Poorter, H., 1993. Inter-specific variation in growth response of plants to an elevated ambient CO_2 concentration. Vegetation 104/105, 77–97.

Pouget, R., 1981. Action de la temperature sur la differenciation des inflorenceset des flours Durant la phase de predebourrementet de post -debourrement des bourgeous latents de la vigne. Conn.Vigne Vin 15, 65–79.

Pratap, U., Pratap, T., 2002. Warning signals from the Apple Valleys of the Hindu Kush Himalayas-Productivity concerns and pollination problems. In: Shreshtha, A.B.M. (Ed.) Productivity concerns and pollination problems. Centre for Integrated Mountain Development (ICIMOD), PO Box 3226, Kathmandu, Nepal.

Rana, R.S., Bhagat, R.M., Vaibhav, K., Harbans, L., 2012. The Impact of Climate Change on a Shift of the Apple Belt in Himachal Pradesh. In: Navroz, K.D. (Ed.). Hand Book of Climate Change and India: development, politics and governance. New Delhi, Oxford University Press, 51–62.

Rao, M.S., Srinivas, K., Vanaja, M., Rao, G.G.S.N., Venkateswarlu, B., Ramakrishna, Y.S., 2009. Host plant (*Ricinus communis* Linn.) mediated effects of elevated CO_2 on growth performance of two insect folivores. Current Science 97(7), 1047–1054.

Robinson, E.A., Geraldine, D.R., Jonathan, A.N., 2012. Tensely Review: A meta-analytical review of the effects of elevated CO_2 on plant arthropod interactions highlights the importance of interacting environmental and biological variables. New Phytologist 1–15.

Rogers, H.H., Dahlman, R.C., 1993. Crop responses to CO_2 enrichment. Vegetatio 104/105, 117–31.

Schaffer, B., Whiley, A.W., Searle, C., Nissen, R.J., 1997. Leaf gas exchange, dry matter partitioning and mineral element concentration in mango as influenced by elevated atmospheric carbon dioxide and root restriction. Journal of the American Society of Horticultural Science 122, 849–855.

Sharma, J.P., Khajuria, D.R., 2005. Distribution and activity of grubs and adults of apple root borer, *Dorysthenes hugelii* Redt. Acta Horticulture 2(696), 387–393.

Sharma, S.C., Roy, R.K., 2010. Impact of global climate change on floriculture in India. Enviro News 16(1), 1.

Sharma, S.K., Devi, N., Raj, D., 2002. Abiotic factors affecting abundance of diamond back moth, *Plutella xylostella* (Plutellidae). Journal of Insect Science 15 (2), 9–11.

Shu, Z.H., Sheen, T.F., 1987. Floral induction in axillary buds of mango (*Mangifera indica* L.) as affected by temperature. Scientific Horticulture 31, 81.

Singh, J., 2003. Low productivity trends in apple growing state of India. Himachal Pradesh: contributing factors. In: Jindal, K.K. (Eds.). Apple farming and livelihoods in the Himalayas 43–58.

Son, C., Han, J.H., Cho, J.G., Kim, S.H., Chang, E.H., Oh, S., Moon, K.H., Choi, M., 2014. Effects of the elevated temperature and carbon dioxide on vine growth and fruit quality of Campbell early grapevines (*Vitis labruscana*). Korean Journal of Horticulture Science and Technology 32(6), 781–787.

Sood, A., Gupta, P.R., 2005. Studies on seasonal abundance of woolly apple aphid and its natural enemies in the mid hills of Himachal Pradesh. Acta Horticulture 2(696), 395–398.

Sridhar, V., Krishna Kumar, N.K., Verghese, A., 2008. Implications of climate change with special reference to management of horticultural crop pests. In: Lal, S.S., Govindakrishnan, P.M., Dua, V.K., Singh, I.F., Pandey, S.K. (Eds.). Impact Assessment of Climate Change for Research Priority Planning in Horticultural Crops. Central Potato Research Institute (Indian Council of Agricultural Research) Shimla 171001, H.P. (India), 206–207.

Srinivasa, R.M., Rama Rao, C.A., Vennila, S., Raju, B.M.K., Srinivas, K., Padmaja, P.C.M., Rao, A.V.M.S., Maheswari M Rao, V.U.M.,Venkateswarlu, B., 2012. Meta analysis of impact of elevated CO_2 on host-insect herbivore interactions. Research Bulletin 02/2012. Central Research Institute for Dry land Agriculture (CRIDA) Hydrabad, India, 48.

Stiling, P., Cornelissen, T., 2007. How does elevated carbon dioxide (CO_2) affect plant herbivore interactions? A field experiment and Meta analysis of CO_2-mediated changes on plant chemistry and herbivore performance. Global Change Biology 13, 1823–1842.

Stover, R.H., Simmonds, N.W., 1972. Bananas. Longmans Scientific and Technical, London, 228–233.

Sun, P., Mantri, N., Lou, H., Hu, Y., Sun, D., 2012. Effects of elevated CO_2 and temperature on yield and fruit quality of strawberry (*Fragaria*×*ananassa* Duch.) at two Levels of nitrogen application. Plops one 7(7), 41000.

Thakur, J.R., Dogra, G.S., Gupta, P.R., 1992. Population trends and dispersal behaviour of woolly apple aphid, *Eriosoma lanigerum* (Haus.). P. 284–290. In: Chadha, K.L., Uppal, D.K., Pal, R.N., Awasthi, R.P., Ananda, S.A. (Eds.). Emerging Trends in Temperate Fruit Production in India, NHB Jach. Communication. NO. 1. National Horticulture Board, Gurgaon, India.

Thomas, C.D., Cameron, A.,Green, R.E., 2004. Extinction risk from climate change. Nature 427(6970), 145–148.

Trumble, J.T., Butler, C.D., 2009. Climate change will exacerbate California insect pest problems. California Agriculture 63, 73–78.

Turner, D.W., Fortescue, J.A., Thomas, D.S., 2007. Environmental physiology of the banana (*Musa* sp.). Brazilian Journal of Plant Physiology 19, 463–484.

Vedwan, N., Robert, E.R., 2001. Climate change in the Western Himalayas of India: A study of local perception and response. Climate Change Research 19, 109–117.

Verma, S.C., Kanwar, H.S., Joshi, A.K., 2008. Population build up of cabbage aphid, *Brevicoryne brassicae* L. on cabbage in relation to weather factors. Himachal Journal of Agricultural Research 39(2), 47–49.

Walther, G.R., Post, E., Convey, P., 2002. Ecological responses to recent climate change. Nature 416 (6879), 389–95.

Wang, S.Y., Bunce, J.A., 2004. Elevated carbon dioxide affects fruit flavor in field grown strawberries (*Fragaria×ananassa* Duch). Journal of Science, Food and Agriculture 84, 1464–1468.

Went, F.W., 1953. The effect of temperature on plant growth. Annual Review of Plant Physiology 4, 347–362.

Wilson, L.A., Gomes, P.I., 1996. Influence of high temperature stress on postharvest quality of processing and non-processing tomato cultivars. Journal of Food Quality 19, 41–55.

Wurr, D.C.E., Fellows, J.R., Phelps, K., 1996. Investigating trends in vegetable crop response to increasing temperature associated with climate change. Scientia Horticulture 66, 255–263.