Approaches to mitigate climate change through studies on plant responses

Chongtham Allaylay Devi and Brij Bihari Pandey
Corresponding author email: chongthamallaylaydevi@gmail.com

Introduction

- ✓ A significant change in climate at global and national level is certainly impacting our crop production and quality.
- ✓ But understanding of impact of climate change on perennial horticultural production system and the potential effects on crop quality have drawn a little attention of researchers.
- ✓ The consequences of such rapid change are - global warming, change of seasonal pattern, excessive rain, melting of ice cap, flood, rising sea level, drought etc. leading to extremity of all kinds.
- ✓ Decrease in potential yields is likely to be caused by shortening of the growing period, decrease in water availability.
- ✓ High humidity (85-90%), moderate temperatures (maximum temperature of 25-26°C and minimum of 18-20°C) provided favourable condition for the initiation of disease (Chhata *et al*., 2006).

WHY CLIMATE CHANGE A CONCERN ?

- ✓ Rise in global average surface temperature of 1.0 to 3.5 degrees Celsius by 2100.
- ✓ Sea levels to rise 7-23 inches by the year 2100.
- ✓ Carbon dioxide expected to be 100% higher in 2100.
- ✓ Annual river run off and water availability will increase at high latitudes and decrease in some dry regions at mid-latitudes and in the tropics.
- ✓ Changes in rainfall and the disappearance of glaciers.
- ✓ The ability of ecosystems to naturally adapt to changes in climate is likely to be severely reduced

Climate Change

- ✓ Evidences have shown that human activities are changing the climate.
- ✓ The main human influence on global climate is likely to be emission of greenhouse gasses (GHG) such as carbon dioxide (CO_2) and methane (CH_4).
- ✓ The global increase in carbon dioxide concentration are due primarily to fossil fuel use and land use change, while those of methane and nitrous oxide are primarily due to agriculture.

Adaptation and Mitigation

- ✓ Adaptation : Adaptation is the process through which people reduce the adverse effects of climate and adaptation measures are meant to protect a community against projected climate change impacts.
- ✓ Mitigation : A human intervention to reduce the sources or enhance the sinks of greenhouse gases, for example, reducing the carbon footprint of business operations by cleaner fuels, reducing electricity consumption, etc.

Stress ?

Stress is an external factor that exerts a disadvantageous influence on the plant and is measured in relation to plant survival, crop yield, growth (biomass accumulation), which are related to overall growth.

Two types i.e. Biotic and Abiotic

Stress & Crops !!

- ✓ Stresses (Biotic and abiotic) can reduce average plant productivity by 65 to 87% (Sade *et al*., 2011) depending on the crop.
- ✓ Climate change have a severe impact on the abiotic stresses which ultimately affects the growth and development of fruit crops.
- ✓ Proper use of breeding approaches to abiotic stresses can reduce the losses in productivity and cost of cultivation.

Abiotic stress

The negative impact of environmental factors on plant growth and yield.

Biotic stress

Biotic stress is stress that occurs as a result of damage done to plants by other living organisms

ABIOTIC STRESS

Any adverse factor acting on physiological processes/ biochemical activity of the plants is called as abiotic stress

Environmental conditions that can cause stress

- ✓ Water-logging & drought
- ✓ High or low temperatures
- ✓ Excessive soil salinity
- ✓ Ozone
- ✓ Low oxygen
- ✓ Phytotoxic compounds
- ✓ Inadequate mineral in the soil
- ✓ Too much or too little light

Abiotic stress due to climate change in horticulture

1. Increasing temperature
    - ✓ Heat stress
    - ✓ Drought
2. Changes in rainfall pattern
    - ✓ Drought
    - ✓ Flooding
    - ✓ Salinity

Characteristics of abiotic stresses

- ✓ Unpredictable occurrence
- ✓ Some stresses are impossible to manage
- ✓ One stress may increase or decrease the level of another stress
- ✓ Differential response of plant spp. to a given stress
- ✓ Effects generated by one abiotic stress may overlap with some effects of another stress

PLANT RESPONSE TO STRESS

- ✓ Stresses trigger a wide range of plant responses
- ✓ Altered gene expression
- ✓ Cellular metabolism
- ✓ Changes in growth rates and crop yields

Changes in gene expression to stress

- ✓ A stress response is initiated when plants recognizes stress at the cellular level.

- ✓ Stress recognition activates signal transduction pathways that transmit information within the individual cell and throughout the plant .
- ✓ Changes in gene expression may modify growth and development and even influence reproductive capabilities

Stress resistance mechanisms

- ✓ Avoidance
  - o prevents exposure to stress
- ✓ Tolerance
  - o permit the plant to withstand stress
- ✓ Acclimatization
  - o alter their physiology in response to stress

Morphological mechanism for providing drought avoidance and tolerance

- ✓ Earliness
- ✓ Reduced in clustering
- ✓ Leaf rolling, folding, shedding, leaf reflectance
- ✓ Hairiness
- ✓ Color of leaves
- ✓ Wax coating
- ✓ Root systems

Mechanism of resistance

Supercooling

- ✓ In plants cooling of water below 0° C without ice crystal formation is called super cooling.
- ✓ or Cytoplasm cooling without ice formation.
- ✓ It is possible because internal ice –nucleators are absent
- ✓ By increasing solute concentration which will increase freezing point.
- ✓ By removing water from cells

Tolerance Mechanism

1. Anti freeze proteins (AFP)
- ✓ Declines rate of ice crystal growth
- ✓ Lowers the efficiency of ice nucleation sites
- ✓ Lowers temp. at which ice forms

2. Osmoprotectants
- ✓ Osmolytes- quarternary amines, amino acids, sugar alcohols
- ✓ Balances the osmotic potential of externally increased osmotic pressure

3. Cell wall/membrane porosity : water should remain in apoplast.
4. Increase in unsaturated fatty acid in membrane
5. Short stature : plant absorbs ground radiation
6. Low leaf area and higher leaf thickness
7. Higher root to shoot percent
8. Dormancy

Physiological Responses to Climate Change

- ✓ Climate change significantly affect plant function and via four main impacts

1. Increased atmospheric CO_2 concentrations
2. Changes in air temperature
3. Changes in water supply

4. Changes to the radiation regime

Increased CO_2 levels

- ✓ Carbon dioxide (CO_2) is the most important anthropogenic gas.
- ✓ Its annual emissions have grown by about 80% between 1970 and 2004 (IPCC 2007).
- ✓ CO_2 rise, climate change and the hydrological cycle affected by climate change.
- ✓ Also affected directly by changing CO_2 concentration ("Physiological Forcing")
- ✓ Increased CO_2 affect the transpiration.
- ✓ The level of CO_2 concentration in the atmosphere determines the degree of stomatal opening and hence transpiration rate.
- ✓ Specifically, if CO_2 levels increase, fewer stomata open and the rate of transpiration decreases.
- ✓ In anthropogenic climate change, the higher temperatures leads changes in the variability of precipitation, water stress that plants suffer potentially reducing photosynthesis and growth.
- ✓ The higher concentrations of CO_2 in the atmosphere will reduce stomatal opening and hence increase plants resilience to water stress.
- ✓ The rising levels of atmospheric CO2 will result in more output of N2O from upland soil and of CH4 from rice field.
- ✓ The reduced in plant transpiration under conditions of elevated CO2 , resulting in increased soil moisture.
- ✓ Together with increased root biomass, this leads both to greater denitrification (and hence increased N2O emission) and to more methanogenic activity (and hence increased CH4 emission).
- ✓ The pronounce effect of the increased CO_2 will be on C_3 plants and that too will be the positive one.
- ✓ But the effect of elevated CO_2 will not be too profound for the C_4 and CAM plant species, almost due to their efficiency in utilization of CO_2 in low CO_2 levels, hence will not be much benefited.
- ✓ The positive effect on the C_3 plant will be due to availability of high CO_2 for photosynthesis and reduction in Photorespiration due to less abundant O_2 due to partial closure of stomata.
- ✓ C_3 - strongest growth response to elevated CO_2
- ✓ C_4 - smallest growth response and
- ✓ CAM - intermediate responses .

Mitigation approaches

- ✓ The increased CO_2 if has beneficial effect it must remit with the long term elevation to, which is the genotypic character.
- ✓ The response of the genotype under long term elevated CO_2 levels must be well studied and also at the same time selection of such genotypes will be used in future breeding programme.
- ✓ Similarly, the yield increase should not be based on the increase of biomass but, the selection should be in terms of harvest index.
- ✓ The high HI expected to have greater sink for Carbohydrates in relation to photosynthetic capacity thus been more responsive to elevated CO_2.

Practicing agro-forestry

- ✓ It can promote soil carbon sequestration while also improving agro-ecosystem function

and resilience to climate extremes by enriching soil fertility and soil water retention.

- ✓ Producing bio-energy—can lead to reduced greenhouse gas emissions via substitution of fossil fuels.

Increased atmospheric temperature

- ✓ The major effect of global warming detrimental to the plants will be the increased temperature.
- ✓ All the plant growth stages are more prone to the temperature and in all the flowering and the grain filling stages .
- ✓ The increased temperature coupled with the elevated CO_2 will be reduced stomatal aperture which will transpire less water i.e. the transpiration will be less, which cannot compensate rate of cooling over the increasing leaf temperature and the leaves starts senescence.
- ✓ The overall crop duration will be reduced and hence plants cannot sink the matter what we can call it as yield.
- ✓ Rising temperatures, can lead to negative impacts such as heat stress, especially in areas at low-to-mid latitudes already at risk today.
- ✓ However, they can also lead to positive impacts, such as an extension of the growing season in high-latitude regions that are currently limited by cold temperatures.

Impacts Higher temperatures

- ✓ The studies indicate small beneficial effects on crop yields in temperate regions corresponding to local mean temperature increases of 1–3°C and associated CO_2 increase and rainfall changes.
- ✓ By contrast, in tropical regions, models indicate negative yield impacts for the major crops even with moderate temperature increases (1–2°C).
- ✓ Further warming projected for the end of the 21st century has increasingly negative impacts in all regions.

Effects of temperature extremes

Wheat :

- ✓ Extreme cold may kill plant at chilling temperatures (below 5°C) and hot temperatures (above 30°C) at anthesis can damage pollen formation, which in turn reduces grain set and can decrease yield.

Rice :

- ✓ Higher temperature reduce spikelet fertility mainly due to spikelet sterility induced during flowering because flowering in rice usually occurs at midday. (Japonica rice)

Cotton :

- ✓ Increase in temperature shortening of developmental time during the boll growth period and this results in smaller bolls, lower yields and poor quality lint.

(Hodges *et al*., 1993)

Mitigation approaches

- ✓ For breeding approaches such as introducing the heat tolerance genes that are more present in the wild relatives of the various crop species.
- ✓ The same may be either easily transferred in to the cultivated species or if not, by use of biotechnology it is possible.
- ✓ To introduce the C_4 cycle in to the C_3 crop plants to harness the potential to withstand the wider temperature range and more source to sink relation.
- ✓ Introduction of heat shock proteins in the chloroplast will provide the protection to some

extent.

- ✓ Agronomic practices - manipulating the sowing dates, irrigation scheduling may also can be implemented to escape the temperature sensitive growth stage e.g. Flowering and grain filling stage

Changed pattern of precipitation

- ✓ The effect of climate change will increase precipitation in future, its distribution will be erratic and less predictive lead to flooding in one region and stress on the other.
- ✓ The theoretical assumption on plant response indicate that the water use efficiency of the crop plants will increased may be due to the reduced stomatal aperture and the transpiration losses will be reduced.
- ✓ Changes in precipitation patterns like extremes droughts and flooding leading to possible negative impact for land-production systems.
- ✓ At the same time affecting plant productivity will be linked to simultaneous temperature and precipitation changes that influence soil water status and the ratio of evaporative demands to precipitation.

Mitigation approaches

- ✓ In severe stress areas shift to the adapting drought tolerant crops species e.g. like Bajra, Sorghum
- ✓ By genetic manipulation of the genetic make of the crop plants either introduction of some novel genes for drought resistance or tolerance from the wild relatives as well as that is present in vast germplasm resources by conventional breeding or with use of biotechnological tools or by genetic engineering.
- ✓ The problem with some extend can be resolved by proper water conservation practices both on field basis as well as planning basis. Reducing N_2O emissions—can lead to improved groundwater quality

(Reddy and Hodges, 2000)

Radiation

- ✓ With drying conditions and an increase in non-rain days predicted that there will changes in cloudiness.
- ✓ Two primary changes in the radiation environment.

i. Less cloudy conditions result in greater amounts of incoming shortwave radiation being received at the surface.

ii. More direct radiation than diffuse radiation.

- ✓ The ratio of direct to diffuse radiation will change the ecohydrological functioning of vegetation.
- ✓ Wetter sites - receive less total radiation and have relative higher proportions of diffuse radiation (more cloud cover).
- ✓ Drier sites - receive more total radiation and have lower proportions of direct radiation (less cloud cover).

Salinity

- ✓ Due to increased sea level in coastal area, increase in salinity will be the major problem.
- ✓ Due to melting of ice glaciers the sea level will rise, the coastal areas then will face the salinity problems.
- ✓ Ocean acidification Changes in pH over the last 25 million years
- ✓ Oceans will become: warmer; more acidic; less diverse; and over exploited.
- ✓ Excessive soil salinity reduces productivity of many agricultural crops, including most

vegetables which are particularly sensitive throughout the ontogeny of the plant.

- ✓ Physiologically, salinity imposes an initial water deficit that results ion-specific stresses resulting from altered K+/Na+ ratios, and leads to a build up in Na + and Cl - concentrations that are detrimental to plants.
- ✓ Salt stress reflected in loss of turgor, growth reduction, wilting, leaf curling and epinasty, leaf abscission, decreased photosynthesis, respiratory changes, loss of cellular integrity, tissue necrosis, and potentially death of the plant.

Mechanism of tolerance

- Salt reabsoption and retranslocation
  - ✓ Xylem to phloem
  - ✓ Cambium to root cells
  - ✓ Casperian strip (suberine content)
- Salt exclusion or ion homostasis
  - ✓ Accumulation of Na+ ion in cytosol
  - ✓ Low ion uptake by roots
- Vacuolar compartmentation
  - ✓ Deposition of salts in vacuoles
- Osmotic adjustment
- Salt glands and bladders (halophytes)
- Trichomes – Pineapple
- Salt accumulation
- Transport of excess toxic ions to older part which soon die off.
- Young tissues are saved from salt toxicity

Mitigation approaches

- ✓ The accumulation of polyols (manitol , sorbitol , inositol and their derivatives) related to drought and salinity stress tolerance in many plant species .
- ✓ The model species Arabidopsis and tobacco are not manitol accumulators and in this respect are attractive candidates for transformation.
- ✓ Tobacco transformed to express mt1D into chloroplasts showed oxidative stress tolerance .
- ✓ Earlier, transgenic tobacco plants carrying bacterial gene coding for manitol-1-phosphatedehydrogenase (mt1D) accumulated manitol in their cytoplasm and were with enhanced biomass growth under salt stress
- ✓ Proline, in abiotic stress conditions it increases in plants E.g. Solanaceae species an increase their proline pool by more than two magnitude in stress condition.
- ✓ Glycinebetaine Quaternary ammonium compound in plants, its accumulation in abiotic stress response and acts as osmoprotectant by stabilizing both the quaternary structure of proteins and the highly ordered structure of membranes .

(Djilianov et al., 2005)

How this changing climate effect fruit crops

Temperature

- ✓ Higher temperature speed plant growth and development in annual crops
- ✓ In perennial crop, being grown in a climate near its optimum, a temperature increase of several degrees could reduce photosynthesis and shorten the growing period affecting the productivity e.g. banana.
- ✓ In areas where current temperatures are below optimal for specific crops, there will be a

benefit, while in areas where plants are near the top of their optimal range, yields will decrease .

- ✓ Even a minor climate shift of 1-2^{o} C could have a substantial impact on the geographic range of these crops. As fruit crops are perennial moving production area is difficult.

Carbon dioxide

- ✓ It is accepted that the atmospheric CO2 is increasing exponentially and will likely to double i.e. about 700 ppm within the next century.
- ✓ This has a beneficial effect on plants and increase productivity.
- ✓ This is not universal as the biochemistry of photosynthesis differ among plant spices.
- ✓ C3 plants benefit much more from increase in CO2 than C4.
- ✓ Build up of sugar in the leaves giving a negative feed back on photosynthesis and benefits from elevated CO2 become minimal.

Precipitation : Rainfall and Snowfall

Rainfall

- ✓ Change to India's annual monsoon are expected to result in severe droughts and intense flooding in parts of India.
- ✓ This change create problems for field operation, more compaction of soil, and possible crop losses due to lack of oxygen for roots and disease problems associated with wet condition
- ✓ Trend over the decreased amounts of annual rainfall in Kullu valley- the attribute on which the colour of an apple mostly depends and regulation of moisture stress.

Snowfall

- ✓ On set of early snow in December and January had occurred more infrequently overtime and extended through the months of Feb. and March.
- ✓ Early snow contributes nitrogen for plant use, replenish soil moisture and prevent humidity build up.
- ✓ Amount of snow determines the number of chilling hours and thereby the time of bud break

Adaptation

- ✓ Develop climate-ready crop varieties
- ✓ Increase water saving technologies
- ✓ Changing planting date and increased use of integrated farming system
- ✓ Crop diversification
- ✓ Provide more non-crop flowering resources in the field
- ✓ Integrated pest management
- ✓ Crop insurance
- ✓ Improved weather-base agro-advisory and nutrient management
- ✓ Harnessing the indigenous technical knowledge of fruit growers

Mitigation measures

- ✓ Reduce emissions of greenhouse gases
- ✓ Intensive increase in reforestation
- ✓ Restoration of degraded lands
- ✓ Increased use of composts
- ✓ Increase biomass to produce energy
- ✓ Land management strategies to increase soil carbon storage

Strategies for mitigating effect of climate change on Horticultural Crops

Breeding strategies

- ✓ Pheno-typing of all important fruits genetic wealth to enhancing temperature, moisture stress and genetic enhancement for tolerance to biotic and abiotic stress.
- ✓ Varieties and rootstocks will be evaluated under controlled temperate moisture stress etc. gradient to identify suitable cultivars of all major fruit crops. Experiments on varietal evaluation will also be conducted under natural conditions at different altitudes/conditions with natural variations in temperature and moisture falling under various agro-climatic zones of the countries.
- ✓ Marker assisted selection and development of transgenic having resistance to biotic and abiotic resistance.
- ✓ Development of genotypes having resistance to heat and drought.

Agronomic management strategies

- ✓ Assessment of the vulnerability and climate risks associated with tropical and subtropical fruit production in sub-tropical region.
- ✓ Development of cropping systems under various agro-climatic conditions.
- ✓ Improvement in the irrigation and drainage systems.
- ✓ Development of appropriate tillage and intercultural operations.
- ✓ Integrated nutrient management.
- ✓ Integrated pest management.
- ✓ Integrated weed management.
- ✓ Development of water harvesting techniques.

Biotechnological innovative strategies

- ✓ Molecular characterization for various traits in relations to biotic and abiotic stress.
- ✓ Transformation of plants from C_3 to C_4 plants.
- ✓ Gene pyramiding against biotic and abiotic stress.
- ✓ Engineering for herbicide resistance.
- ✓ Engineering for disease resistance.
- ✓ Engineering for insect-pest resistance.
- ✓ Engineering for improving post-harvest traits.
- ✓ In vitro conservation of rare and useful species for future use.

Horticulture/Fruit based cropping system

- ✓ Agri-silvicultural system.
- ✓ Agri-horticulture system (Custard apple and also pomegranate and amla are other fruit crops suitable for this system).
- ✓ Agri-horti-silvicultural system.
- ✓ Horti-pastoral: (aonla based hortipastoral system).
- ✓ Inter cropping annual crops under fruit trees.
- ✓ Integrated Farming system.

Mitigation strategies for higher CO_2/ GHG

- ✓ Assessment the carbon sequestration potential of perennial fruit crops production system.
- ✓ To participate in the international dialogue about greenhouse gas emissions management, global warming and sustainable energy development.
- ✓ The improvements in the efficiency of electricity generation, transmission and distribution.
- ✓ The use of fuels with lower carbon content, e.g., natural gas, Gobber gas.
- ✓ Fuel switching, appliance efficiency and use of renewable energy.

- ✓ Tree planting and forest management.
- ✓ Waste processing.

Future Research Strategies For Optimizing Production Under Changing Climate Scenario

Crop improvement strategies

- ✓ Utilizing the current and future regional climatic scenarios of the tropical, subtropical and temperate region a micro-level survey of agro-climatic zones of country should be conducted to identify sensitive regions with high vulnerability with respect to different fruit crop.
- ✓ Evaluation of wild species should be probed thoroughly, which could be a source of resistant genes for tying over adversaries of the temperature.
- ✓ Evaluation of local types and landraces should be carried out to locate useful genotypes.
- ✓ Development of stable genotypes, which can perform across different environments within the region, is needed. There is a need to develop and test the performance of different genotypes across several environments so that their suitability can be judged.
- ✓ Development or location of rootstocks that can tolerate biotic stresses induced by temperature regimes is needed. In many crops, rootstocks have helped in combating the biotic stress induced by varying temperature conditions.
- ✓ Introduction of low chilling cultivars of pome, stone and nut fruits.
- ✓ Marker assisted selection and development of transgenic having resistance to biotic and abiotic resistance.
- ✓ Development of genotypes having resistance to heat and drought.
- ✓ Biotechnological approaches for multiple stress tolerance will be standardized.

Development of agro-techniques

- ✓ Adoption of improved agro-techniques like mulching and cover crops in orchards will help in bringing down the orchard temperature.
- ✓ Use of precision farming methods.
- ✓ The phenology of all major crops under changing climate will be monitored.
- ✓ In-situ soil moisture conservation practices including indigenous technical know-how will be validated to mitigate the impact of drought.
- ✓ Development of suitable agronomic adaptation measures for reducing the adverse climate related production losses.
- ✓ Study the impact of climate change and development of technologies on water productivity .
- ✓ Identify and develop good practices to enhance the adaptation of crop to increased temperature, moisture and nutritional stress.

Plant protection strategies

- ✓ Assessment of the pest and disease dynamics, study of disease triangle and development of prediction models.
- ✓ Strengthen surveillance of pest and diseases.
- ✓ Development of eco-friendly pest-ecologies and management strategies and early warning systems.

Post-harvest management strategies

- ✓ Development of cost effective storage techniques. Infrastructure like cold storages, refrigerated vans is extremely important to reduce transportation losses.
- ✓ Development of varieties having longer shelf life.
- ✓ Studies on mitigation of postharvest spoilage and simulation models need to be developed for forecast of field diseases and spoilage under post- harvest loses.

HRD & creating awareness

- ✓ Organize seminars/ symposia/ trainings and conduct field demonstrations, on effective climate resilient technologies.

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