Volume 1

Climate Dynamics in Horticultural Science

Principles and Applications

Editors

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Apart from his professional career, he was also Chairman and Member Secretary of various committees constituted by the Government of India as well as state governments. He has guided 18 PhD students and 21 MSc students in the field of horticulture and has published 124 book chapters, 19 books, and 109 research papers of national and international repute. Dr. Choudhary has represented India at various international forums in the capacity of Chairman and Member. He was also the Chairman of the Codex Committee of the Scientific Committee for Organic Standard of Ministry of Commerce. He has been conferred with 15 awards from various scientific and nonscientific organizations and government committees for his outstanding contribution in the field of horticulture/ floriculture. He has also been awarded the Fellowship of Horticultural Society of India. Dr. Choudhary in his 30 years of academic, research, and administrative career has visited more than 15 countries to participate in various professional meetings.

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LIST OF ABBREVIATIONS

ABA	Abscissic Acid
ASP	Amnesic Shellfish Poisoning
AZP	Azaspiracid Shellfish Poisoning
BMPTC	Building Materials and Technology Promotion Council
BVOCs	Biogenic Volatile Organic Compounds
BVP	Bacteria, Viruses, and Parasitic Protozoa
CBF	C-Binding Factor
CFCs	Chlorofluorocarbons
CI	Chilling Injury
CMS	Cell Membrane Stability
CMT	Cell Membrane Thermo Stability
CSRB	Cashew Stem and Root Borers
CWSI	Crop Water Stress Index
DSP	Diarrheic Shellfish Poisoning
EC	Electrical Conductivity
ECU	Effective Chill Units
ESP	Exchangeable Sodium Percentage
ET	Evapotranspiration
FAO	Food and Agriculture Organization
FBD	Fruit Bud Differentiation
FCF	Fungal Culture Filtrate
GDHOC	Growing Degree Hours Celsius
GDP	Gross Domestic Product
GHGs	Green House Gases
GLOFs	Glacial Lake Outburst Floods
GRAS	Generally Recognized As Safe
GWP	Global Warming Potential
HCFCs	Hydrochlorofluorocarbons
HDP	High Density Planting
HSGs	Heat Shock Granules
HSPs	Heat Shock Proteins
ICAR	Indian Council of Agricultural Research

ICFRE	Indian Council of Forestry Research and Education
ICT	Information and Communication Technologies
INM	Integrated Nutrient Management
IPCC	Intergovernmental Panel on Climate Change
IPM	Integrated Pest Management
IWRM	Integrated Water Resource Management
LAR	Leaf Area Ratio
LEA	Late Embryogenesis Abundant
MAS	Marker-Assisted Selection
MSL	Mean Sea Level
NBDA	Nagaland Bamboo Development Agency
NEH	North Eastern Hilly
NO	Nitric Oxide
NPP	Net Primary Productivity
NSP	Neurotoxic Shellfish Poisoning
OA	Osmotic Adjustment
OTC	Open Top Chamber
PR	Pathogenesis-Related
PSP	Paralytic Shellfish Poisoning
PUT	Putrescine
QTL	Quantitative Trait Locus
RCTs	Resource Conserving Technologies
REC	Relative Electrical Conductivity
RH	Relative Humidity
RWC	Relative Water Content
SA	Salicylic Acid
SD	Short-Day
SLA	Specific Leaf Area
SNP	Sodium Nitroprusside
SPD	Spermidine
SPM	Spermine
TMB	Tea Mosquito Bug
TYLCV	Transfer Tomato Leaf Curl Virus
UNCED	UN Conference on Environment and Development
UNFCCC	United Nations Framework Convention on Climate Change
WHO	World Health Organization
WUE	Water Use Efficiency
YP	Yield Potential

LIST OF SYMBOLS

A	photosynthesis
E	transpiration
N	nitrogen
P	phosphorus
AN	carbon assimilation
gm	mesophyll conductance
gs	solute potential
Si	silicon
Ta	air temperature
T_c	canopy
CO	carbon monoxide
F0	base fluorescence
CH_4	methane
CO_2	carbon dioxide
N_2O	nitrous oxide
SF_6	sulphur hexafluoride
SO_2	sulphur dioxide
$^1O^{2-}$	singlet oxygen
O_{2-}	superoxide anions
O_3	ozone
H_2O_2	hydrogen peroxide
b_l	biochemical limitation
K_l	leaf diffusive conductance
Ψ_{leaf}	leaf water potential
Ψ_p	turgor potential
Ψ_s	rate of change in solute potential

PREFACE

Climate change and increased climate variability in terms of rise in temperature, shifting rainfall pattern, and incidences of extreme weather events like severe drought, devastating flood, etc., have now started posing a real threat to the production of agricultural/horticultural crops and natural resource management in the several countries. The rate of climate change and warming expected over the next century is anticipated to be more than what has occurred during the past 10,000 years. Predictions clearly indicate that the impact of the climate change is going to be more intensified in coming years. Climate change is already affecting—and is likely to increase—invasive species, pests, and disease vectors, all adversely affecting agri-horticultural crops productivity. Climate change makes agriculture more difficult to sustain with higher frequencies of floods, droughts, heat weaves, erratic rainfall, increased salinity, as well as a rise in sea level. These phenomena have direct impact on crop yield, quality, and consequently food security. Attempts to develop pioneering solutions to adapt climate change and address its own needs are required urgently.

Horticulture has emerged as the most dynamic and indispensable part of agriculture, offering a wide range of choices to farmers for crop diversification and much-needed nutrition for people. The changing of dietary habits of people with an improved standard of living has increased the demand for horticultural products. Horticultural crops are sometimes more vulnerable to the changed scenario of climatic aberrations. The dependence of crops on natural resources is sometime more pronounced on cereals or pulses, and so is their reaction to the extreme variations in seasonal temperature. Increase in productivity of horticultural crops is essentially required to cope with the demand of the increasing populace with diminishing per capita arable land and water, with degrading soil resources, and with expanding biotic stresses, and efforts to mitigate the adverse impact of climate change on productivity deserve attention of crop scientists/growers. Meeting the goal of enhanced production of nutritious fruits and vegetables in altered climatic conditions is achievable, but the strategies that enhance tolerance of crops to such variability in the growing environment of this region are yet to be formulated.

This book, *Climate Dynamics in Horticultural Science: Volume 1: Principles and Application*, deals with the basic concepts of climate change and its effects on horticultural crops. Different effects of climate change and their possible mitigation strategies are discussed. This book—along with its companion volume, *Volume 2: Impact, Adaptation, and Mitigation*—will be a standard reference work for policymakers who are charged with developing programs and legislation. Moreover, researchers will also understand the implications of climate change to provide a sound basis for decisions on adaptive strategies that enhance the agri-horti sector's ability to manage climate risks and take advantage of opportunities.

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CHAPTER 1

HI-TECH HORTICULTURE AND CLIMATE CHANGE

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CONTENTS

1.1 INTRODUCTION

Horticulture crops, in general, are more knowledge and capital-intensive than staple crops. Today horticulture in India is a more vibrant and dynamic sector than ever before. It contributes nearly 30% of the agricultural GDP. Annual production of 74.8 million tons of fruits, 146.5 million tons of vegetables and 1.03 million tons of loose flowers (NHB, 2011) have to be increased substantially to cope with increasing demand of these commodities due to increasing population and expanding domestic and external markets. Short-term growth and long-term viability of any sector are critically dependent on access to technical knowledge, the ability to adapt that knowledge to local conditions and the flexibility to develop new production systems as market conditions change. Successful production of a horticultural crop depends on understanding of various factors affecting plant growth, fruiting, and manipulation of these factors for higher productivity and improved quality cultural activities.

In the past three decades aspects like plant density, planting time, manuring, irrigation, weed management, intercropping, training and pruning, disease and insect pests management have attracted attention of the scientists and a great deal of work has been done on standardizing these practices for higher productivity per unit area and possible reduction in the cost of production. In the recent past, the growth of horticulture sector has been far better than the overall growth of the agriculture sector. However, expanding the scale of horticultural production is often complicated by substantial problems. In the last 20–25 years, research and development scenario in horticulture has gained momentum with an impressive public and private support. The research institutes have developed a large number of technologies to improve the productivity and quality of fruits, vegetables and flowers. Some of these technologies require high degree of instrumentation and involves specific skills and accuracy to perform them. They are generally considered under hi-tech horticulture.

1.2 CLIMATE CHANGE

There are growing evidences to show that climate change has already affected agricultural productivity and will put increasing pressure on agriculture in the coming decades. Record breaking extreme weather events in the recent past different parts of the world offered a glimpse of the challenges climate change would bring. Analysis of recorded climatic datasets clearly indicates that there has been a 0.3 °C to 0.6 °C warming of earth surface since the late nineteenth century. The average global temperature has increased by 0.8 °C in the past 100 years and is expected to rise by 1.8 °C to 4.0 °C by the year 2100. For Indian region (South Asia), the Intergovernmental Panel on Climate Change (IPCC) has predicted 0.5 to 1.2 °C rise in temperature by 2020, 0.88 to 3.16 °C by 2050 and 1.56 to 5.44 °C by 2080, depending on the scenario of future development. The atmospheric warming will also be associated with changes with rainfall patterns, increased frequency of extreme events of drought, frost and flooding. Since the late 1970s, there have been increases in the percentage of the globe experiencing extreme drought or extreme moisture surplus.

The Intergovernmental Panel on Climate Change (IPCC) predicts that by 2050, mean temperatures around the planet may rise by between 2 and 5 °C or more and atmospheric CO_2 concentration are likely to be >550 ppm (cf. 380 ppm at present). Tropical and semitropical climates in particular are expected to experience dramatic increases in temperatures, as well as more variable rainfall (Jarvis et al., 2010). Of serious concern is the fact that most of the world's low-income families dependent on agriculture live in vulnerable areas, namely in Asia and Africa. Farmers having small land holdings in India will need to adapt to higher temperatures and shifting precipitation patterns. In addition, climate variability will likely cut into global food production, exacerbating the existing problems of poverty, food insecurity, and malnutrition. Furthermore, the greenhouse gas emissions are once again rising rapidly, making the climate change challenge to food security much greater.

In general, alterations in our climate are governed by a complex system of atmospheric and oceanic processes and their interactions. In the context of crop production, relevant atmospheric processes consist of losses in beneficial stratospheric ozone (O_3) concentration and increasing concentrations of the surface-layer trace gases, including atmospheric carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and sulfur dioxide (SO_2). Surface level O_3; SO_2; and CO_2 have direct impacts on crops, while CO_2, CH_4 and N_2O are critical in altering air temperature.

Particular attention is paid to likely changes on extreme events and sea level alterations. It is reported with high to very high confidence that in the 1990–2100 periods most extreme events will increase in intensity or frequency, or both. The published reports on the subject predict higher maximum temperatures and a greater number of hot days, higher minimum temperatures and fewer cold days, reduced diurnal temperature ranges, more intense precipitation events, increased risk of drought in summer periods, increases in peak wind intensities of cyclones, and increases in mean and peak precipitation intensities of tropical cyclones. On top of that, sea level is predicted to increase by 0.09–0.20 m.

1.3 CONSEQUENCES

The major changes in the earth's atmosphere are the concentrations of CO_2, which have increased by about 25% since the beginning of the industrial revolution. The CO_2 concentration has increased from preindustrial level of about 280 ppm to 393 ppm in 2010. Carbon dioxide enhances photosynthesis and depresses plant respiration; these effects are expected to increase plant growth as well as affecting various other processes. However, a number ofplants physiological processes are also affected by changes in temperature, ozone, ultraviolet radiation, nutrients and water, all of which are variable factors often associated with climatic change.

Weather is the most important cause of year-to-year variability in crop production, even in high-yield and high technology environments. There has been considerable concern in recent years about possibility of climatic changes and their impact on the crop productivity. Today the entire world is suffering from global warming and its consequent climate change. Its impact on productivity and quality of crops has been documented fairly well. Since a crop could be defined as a biological system tailored to give certain products, the product output and quality is bound to vary with change in the growing environment.

Crop productivity will not only be affected by changes in climatically related abiotic stresses (i.e., increasing temperatures, decreasing water availability, increasing salinity and inundation) and biotic stresses (such as increases in pests and diseases), but also changes in the atmospheric concentration of carbon dioxide, acid deposition and ground level ozone. Hence, a key challenge is to assess how crops will respond to simultaneous changes to the full range of biotic and abiotic stresses. Responding to these challenges will require advances in crop research and the adoption of appropriate technologies.

1.3.1 IMPACT ON FRUIT CROPS

The recurrent developmental events of phenology and seasonality in vegetative flushing or bud differentiation distinguish trees from annual or agricultural crops. The fact that trees live over multiple growing seasons implies that every year there is a considerable renewal cost of some organs (leaves and fine roots), and that trees are more responsive or susceptible to climatic changes. When horticultural productivity is the goal, the allocation of resources toward reproductive processes must be maximized. However, the tree must also preserve its growth potential for future years; thus, a delicate C balance must be maintained between vegetative and reproductive needs. In spring, stored sugars and nutrients support actively growing shoots and inflorescences. Competition occurs between vegetative and reproductive meristems, and the fruit is growing essentially on the currently produced photosynthates. Fruits represent a major C sink in tree crops. The relationship between fruit load and photosynthetic activity (Palmer et al., 1997), as well as the effects of several climatic variables, has been intensively studied (Buwalda and Lenz, 1995; Wibbe et al., 1993). Among all tree crops, cultivated fruit trees are the ones most adequately supplied with water and nutrients; thus, there should be few, if any, constraints to a positive CO_2 response (Janssenet al., 2000).

Climatic change effects are not caused by a single factor (e.g., elevated CO_2), but originate from complex interactions among various factors such as atmospheric CO_2, air temperature, nutrient supply, tropospheric ozone level, UV-B radiation, drought frequency, etc. A reduction of stomatal conductance under elevated CO_2 might have a significant effect on water transport in trees, since the latter is roughly proportional to stomatal conductance. Hydraulic conductivity was reported to decrease with elevated CO_2 (Tognetti et al., 1996) but this effect is very species-specific. A decrease in stomatal conductance in response to CO_2 enrichment is commonly observed in many crops. However, under elevated CO_2, the increase in WUE is usually greater than the reduction of stomatal conductance, especially under drought conditions. Among all plant organs, fine tree roots generally show the greatest response to elevated CO_2. In addition to increases in fine-root density, trees may enhance their nutrient uptake capacity through alterations in root morphology and architecture. Trees grown under elevated CO_2 initiate more lateral root primordial, leading to increased root branching and a more thorough exploration of the soil. In addition to changes in fine-root density, morphology and structure, alterations in root functioning are also frequently observed in the changed environments. However, it has been a general observation that the long-lived plants have more time to acclimate to changing environmental conditions than the short-lived organisms. On a time scale, this acclimation might occur in the order of several years. The acclimation process might be influenced by seasonal changes in environmental conditions.

1.3.2 IMPACT ON VEGETABLES

Increasing CO_2 will enhance photosynthesis and improve water-use efficiency, thus increasing yield in most vegetable crops. Relative benefits from increased CO_2 can often be maintained with modest water and N deficiency, but yield benefits on an absolute basis are reduced when water or N limit growth. The impact of increasing temperatures is more difficult to predict. Seed germination will probably be improved for most vegetables, as will vegetative growth in regions where mean daily temperatures during the growing season remain under 25 °C, assuming adequate water is available. Reproductive growth is extremely vulnerable to periods of heat stress in many important vegetable fruiting crops, such as tomato, pepper, bean and sweet corn, and yield reductions will probably occur unless production is shifted to cooler portions of the year or to cooler production regions. This vulnerability results from the shortened duration of grain, storage tissue, or fruit filling and from failure of various reproductive events, especially the production and release of viable pollen. Processing crops, which are sometimes direct-seeded and are more frequently grown in cool-summer areas, are more likely than fresh-market crops to benefit from higher temperatures. In general, crops with a high harvest index, high sink demand, indeterminate growth and long growth seasons are considered most likely to respond positively to the combination of higher CO_2 and temperature. Relatively few crops have been studied, however and cultivars within a crop often differ in their responses, thus making generalizations difficult.

In many crops, high temperatures may decrease quality parameters, such as size, soluble solids and tenderness. For fresh-market vegetable producers, even minor quality flaws can make their crops completely unsaleable in some markets. Reduced or more irregular precipitation will also decrease vegetable yields and quality, although soluble solids and specific weight may increase in some crops. Leafy greens and most cole crops are generally considered to be cool-season crops, so heat stress during the growing season would be detrimental to these species. High-temperature effects on lettuce and spinach and low-temperature effects on cole crops include induction of flowering and elongation of the seed stalk. Perennial crops also require an overwinter cool period. Thus, planting dates, production areas and cultivars may need to be adjusted if temperatures change.

1.4 HI-TECH HORTICULTURE

Hi-tech horticulture is now widely employed for the profitable commercial production of horticultural products. In general, hi-tech horticultural practices include practices that demand high level of precision for application of inputs and management of the crop right from sowing to harvesting. Examples of hi-tech horticulture are biotechnological tools used for characterization and developing new superior strains, cryopreservation, micro propagation, greenhouse or protected cultivation, hydroponics, drip and sprinkler irrigation, fertigation, integrated pest management (IPM), integrated nutrient management (INM), molecular diagnostics, HDP mechanization for harvesting, grading, packing and storage of fruits, vegetables and flowers, and quality management of value-added horticultural products throughout the entire cold chain.

Precision farming of fruits and vegetables is also sometimes synonymous to hi-tech horticulture as it focuses on the very latest techniques and innovations with respect to production of the crops. It implies that the grower knows precisely how to steer his production process to achieve optimal yield and quality of the concerned crop. By combining minimal input with maximal output, without wasting resources, he not only promotes environmental well-being, but also increases his profitability. In this article, discussion is limited to important technologies that are helpful in providing opportunities for reducing the impact of climate change in future, as climate change has been predicted to result in disruption of many farming or crop production systems. The Food and Agriculture Organization (FAO) predicts a 15–20% fall in global agricultural production by 2080. Consequently, developing suitable strategies to mitigate the impact of climate change is one of the biggest challenges for plant scientists today.

1.5 BIOTECHNOLOGY

A rapidly changing climate will require rapid development of new varieties of fruits, vegetables and flowers that are capable to withstand vagaries of the weather. As an adjunct of the well-established conventional approaches of plant breeding, biotechnology can enhance the speed, flexibility and efficiency of developing new hardy cultivars. Important contribution of plant biotechnology would be to improve stress tolerance traits in fruits, vegetables and other crops of commercial value in horticulture. Molecular markers are used to provide greater focus, accuracy and speed in crop breeding programs. In general, the opportunities for enhancing crop performance under stress conditions lie in identifying key traits that require enhancement, stress-relieving candidate genes and the appropriate plant stage of development where enhancement should occur. This process of gene identification and gene expression patterns associated with quantitative genetic traits in crops is becoming more attractive and promising as the scientific community develops and gains access to large-scale genomics resources such as EST (expressed sequence tag) databases, high-throughput gene expression profiling technologies and genomic mapping information. In recent past stress tolerance of plants has been improved through gene transfer, or at least identifies cases in which genetic engineering of plants has shed some light on the mechanisms by which stress tolerance or resistance is conferred.

Further, to improve the ability of crops to cope with existing and new stresses, it is imperative to develop a basic understanding of the mechanisms and processes by which plants respond to biotic and abiotic stresses. Many of the major abiotic stresses arise because of a common biochemical phenomenon, efforts to improve tolerance to one abiotic stress have potential to confer tolerance to other abiotic stresses. Research stations working on horticultural crops are maintaining a large number of germplasms of their mandate crops. They can help in breeding strains resistant to biotic and abiotic stresses. Cryopreservation i.e. storage of tissues, for example, meristem, embryo or recalcitrant seeds, etc. in liquid nitrogen at 196 °C has been adopted for storage of germplasm and to ensures safety of rare or endangered plant spp. This type of storage arrests all metabolic activities resulting in storage of material for a longer time.

In the past two decades, more emphasis has been given to modifying crops with stress tolerance-conferring genes. These efforts have demonstrated enhanced abiotic stress tolerance to drought, salinity, temperature, soil pH, and drought stress, and have provided validation to the concept of enhancing abiotic stress tolerance in crop plants via biotechnology. Biotechnology is thus providing new solutions to old enigmatic problems. We are discovering and understanding how to optimize metabolic pathways and physiological processes in plants to increase crop yield potential and crop production under challenging agricultural environments. Efforts are also under way to improve crop quality and nutritional value for human consumption as well as animal feed.

Climate change is expected to have major effects on population thresholds of microorganisms and disease vectors. The dynamics affecting host-pathogen interactions lead to the selection of new pathotypes or pathogens. They also determine the emergence of new diseases and pests. Increases in yield per unit of area will continue to depend largely on more efficient control of (biotic) stresses rather than on an increase in yield potential. Integrated crop management is therefore the basis for sustainable agriculture. The range of options for adapting to the changes increases with technological advances. Breeding for pest and disease resistance using molecular tools is critical and will remain an essential part of crop improvement programs in horticultural crops.

It is now apparent that the recent advancements in biotechnology are providing the research communities with new tools such as genomics and proteomics that will allow researchers to discover new genes and understand their function in higher numbers, and with greater speed and more precision. The knowledge gained from these technologies has helped bringing more opportunities and tools to solve agricultural problems that once were hard to approach or understand. Several transgenic varieties of horticultural crops showing resistance to biotic and abiotic stresses are available today (Kaur and Bansal, 2008; Mou and Scorza, 2011). However, molecular biology tools will never replace the input and role of crop breeders in improving agronomic traits, but these tools will enable them to be more responsive in both time and breadth of environmentally sensitive traits to meet agricultural market needs and opportunities. Biotechnology tools combined with conventional breeding should position us to be able to take greater care of the production environment and allow us to achieve adequate food production and security for the growing world population.

1.6 MICROPROPAGATION

Fast, large-scale vegetative multiplication of plants by application of tissue culture technique is known as micropropagation. It is used as an accelerated form of clonal propagation and usually conducted in growth chambers. The propagation is completed in several stages under controlled conditions and through this technique large quantity of disease free quality planting materials can be supplied within stipulated time. HDP of crops has necessitated faster multiplication of plants through this technique. Each step of the process can be manipulated by control of the tissue culture environment. Many people consider it as a biotechnology component as it is helpful in faster multiplication of a newly bred, superior cultivar or regeneration of genotypes conserved or kept under cryopreservation. In a situation, when large scale crop devastation occurs due to climatic catastrophes this can be a powerful tool for producing large number of plants of a particular clone or clones. Since most of the operations are performed under room conditions under sterile conditions, the impact of climate change on efficiency of production or multiplication is lesser in magnitude. However, hardening of TC plants at later stages suffers from weather aberrations. Although hardening is also done under polyhouse or nethouse conditions, storms/hurricanes can tear the coverings of these structures and cause substantial damage.

It is expected that more than 100 tissue culture units are operational in public and private sectors in our country, out of which 25% have gone for commercial production of plants. Although all these tissue culture units are having high production capacity, there is a cause for concern because the target crops are the same in all. Many institutions are working on developing protocols in different crops. However, today well-tested protocols are available only in case of banana, papaya, strawberry, orchids and anthuriums. Protocols are also available but not yet commercially adopted in respect of apple, citrus, black pepper, potato, ginger, rose and grape. Bulk of tissue-cultured material being exported is primarily of ornamental plants for which the domestic demand is limited.

1.7 MICRO-IRRIGATION/FERTIGATION

With apparent change in climatic conditions growth rate of plants is expected to be faster due to increased plant temperature, which reduces the window of opportunity for photosynthesis since the life cycle is truncated, whileboth heat and drought stress may inhibit growth directly at the metabolic level. This ultimately is responsible for lower productivity of crops. As frequency of drought like situations is increasing in many areas, efficient irrigation technology like drip or sprinkler irrigation can play a major role in improving productivity of crops not only in drought-prone areas but also in areas receiving normal rains. Drought and salinity are the major and most widespread environmental stresses that substantially constrain crop productivity in bothnonirrigated and irrigated agriculture. Irrigation management practices used to increase crop outputs exacerbate the detrimental impact of salinity in agriculture. In the recent years, the more emphasis has been laid on microirrigation techniques. In majority of the crops, yields for micro irrigation systems were better than surface method of irrigation. Micro irrigation system was found to result in 30 to 70% water savings as compared to traditional irrigation methods (flooding/furrow or check basin) in various orchard crops and vegetables along with 10 to 60% increases in yield. Mulching with drip further enhanced the crop yield to the tune of 10–20% and controlled weeds up to 30–90% (Rajput and Patel, 2008).

Fertilizer solutions can be injected into the irrigation system (fertigation) in commercial crop plantings to avoid stress and poor growth of plants. The water (and some of the fertilizers present) can then be recycled by pumping it back out of the holding tank or pond, after some of the impurities (sand and silt) have settled out. Recycled water has actually been shown to improve plant growth. In experiments with more than 100 species of ornamentals grown in 2.8 L containers, the mean relative growth of plants irrigated with continuously recycled water was 103% over that of the control. Another way to reduce runoff is to use pulse irrigation. In this system, instead of applying one heavy watering daily, a small amount of water is applied five or six times during the day. Very little water escapes from the container or runs off from the field. The production advantage to this is that less fertilizer has to be applied, because there is less leaching. Plant growth may be more effectively maximized by reducing moisture stress than by increasing fertilizer concentration. A fertilizer concentration ranging between 50 and 200 mg/L of nitrogen gives good results for potted plants. Sufficient evidences are available to show that water stress might limit growth more frequently than does limited nutrition under container production of flowering and foliage plants.

1.8 HIGH DENSITY PLANTING

HDP of perennial fruit trees like apple, pear, peach, mango, guava or litchi is considered as one of the technological advancements of recent past as it can lead to cost-output and fruit quality enhancements. The main factors here are intra and inter-row spacing, training system, and canopy and hedgerow profiles. This is perhaps the most important, irrevocable and decisive set of criteria, for these decisions are made before planting and often determine yield and the orchard's overall economic viability. The primary reasons for the adoption of high-density orchard systems have been earlier cropping and higher yields, which translate to higher production efficiency, better utilization of land, and a higher return of investment. Trees in high-density orchards may be free-standing, staked, or supported by a trellis. This is a function of the training system, the tree species the rootstock and cultivar selected, and the goals of the enterprise. Intensive orchards require a greater outlay of capital, labor and managerial skills, especially during establishment. The need for greater investment is a function of the larger number of trees and tree supports and will be especially significant if a wire supported training system is proposed.

The concept of HDP is becoming widespread all over the country, although there are limits to it, and varying constraints linked to given circumstances when the goal is to produce high-quality fruit at competitive prices. It is an approach dictate by two key factors: shorter life-span of the orchard to quickly depreciate start-up outlays (by years 4 to 8 of orchard life) by planting early cropping cultivars, and to establish a management system that will reduce per-unit production costs. Once established, high-density orchards with smaller trees require less labor per unit of fruit produced than low-density orchards. Smaller trees and readily accessible canopies are easier to harvest, and the need for using and transporting ladders is minimize or eliminated. The ability to harvest most of the fruit from ground level is also valuable in pick-your-own operations where the absence of ladders reduces concerns of liability. Pruning is less labor-intensive in many systems, and the trees are easier to manage, provided plant growth is regulated by early and regular cropping.

Pest control in high-density orchards is facilitated because tree canopies are smaller and in many systems (especially trellised ones) are not very deep. This allows enhanced spray penetration into the canopy and reduces the need for large orchard spray equipment. Studies on spray deposits have shown that the coverage of spray materials on the leaf surfaces of trellised and nontrellised high-density trees is better than on standard trees. This, however, varies with the training system. For example, horizontal canopies have reduced spray penetration compared to vertical ones and consequently may have higher insect and disease damage. One of the greatest advantages of dwarf trees is that the interior shaded areas of the trees is greatly reduced on each tree, and with many more trees per hectare, light penetration and orchard efficiency are dramatically increased.

1.9 INTEGRATED NUTRIENT MANAGEMENT

Modern nutrient management practices rely on fine-tuning the application of nutrients of satisfy specific needs of different tree organs at times most beneficial from the standpoint of tree productivity and fruit quality. An improved understanding of how tree nutrient reserves are built up and mobilized leads to fertilizer practices that optimize yield and fruit quality while minimizing excessive vegetative growth. The use of different rootstocks with various abilities to acquire nutrients from the soil is being explored to solve tree nutritional problems via genetic means rather than fertilizer manipulations alone. A better understanding of the genetic control of plant nutrient uptake and translocation on a molecular level will open new frontiers for further improving the efficiency of mineral nutrient acquisition and utilization with the use of less fertilizer. All these modern approaches to plant nutrition are aimed at minimizing or eliminating the environmental pollution that can potentially result from the use of fertilizers. In wake of the changing climatic scenario fertilizer practices will increasingly be assessed by their overall impact on yield, quality of the produce, soil health, and environment.

Accomplishments of the enhanced rate of productivity require that soil quality be either enhanced or at least sustained at the present level. The soil fertility can be managed in complete harmony with sustainable production of the crops by careful analysis of soil and plant tissues. Sophisticated instruments are available to do these analyzes rapidly and draw suitable inferences so that type of fertilizers and their quantity can be decided accurately as per the need of the situation.

Land use pattern and soil management practices during crop production over a period have large impact on soil health and whether the soil functions as a source or as a sink for carbon. Intensive cultivation has been depleting more nutrients than what was added externally through fertilizers. It is therefore not surprising that farmers have to apply more fertilizers to get the same yields. Micronutrients such as sulfur, zinc, manganese, etc. are generally not replaced externally and so have compounded the problem of nutrient deficiency. Integrated use of organics (organic manures and bio-fertilizers) and chemical fertilizers has been found to be promising in not only maintaining and sustaining higher productivity but also in providing stability in crop production.

Integrated nutrient management holds great promise in maintaining sustainability of soil health and its fertility. Use of vermicompost and biofertilizers has been found highly effective in sustaining productivity of the soil. Similarly, use of a consortium of biofertilizers has helped in reducing the recommended fertilizer dose in many horticultural crops. More than 50% micronutrient fertilizers could be saved by mixing them with just 1.0 to 1.2t BGS (Bio-Gas Slurry)/ha. Returning crop residues to soil over long periods has great bearing on its productivity and physicochemical and microbial properties. Crop residues at 50% of straw produced take care of micronutrient nutrition to crops in the long run. Similarly, use of green manure often takes care of micronutrients deficiency in the soil. Under changing climate when there is widespread deficiency of nutrients in the soil, integrated approach for nutrient management would definitely be more sustainable and rewarding.

1.10 INTEGRATED PEST MANAGEMENT

Fruits and vegetables suffer more from residual toxicity of chemicals in their flesh than cereals and pulses, as they are highly perishable and consumed soon after harvest. A plethora of insect pests and diseases frequently invade them. It has been reported that the climatic aberrations can alter pest dynamics of a place. Changing patterns of drought and heat, as well as elevated CO_2 are likely to be accompanied by a change in the whole spectrum of biotic stresses. For most of the commercial crops, more tropical environments are also associated with greater numbers of foliar pests and diseases. Therefore, climate change would be likely to result in increased risk of epidemics (Legrève and Duveiller, 2010). In dry regions, root diseases such as nematode infestation are also problematic since they further reduce the plant's ability to extract scarce water.

Climate change is likely to alter the distribution and severity of soil borne diseases affecting both intensive and low-input agricultural production systems. Naturally occur ring disease suppressive soils have been documented in a variety of cropping systems, and in many instances, the biological attributes contributing to suppressiveness have been identified. While these studies have often yielded an understanding of operative mechanisms leading to the suppressive state, significant difficulty has been realized in the transfer of this knowledge into the development of effective field-level disease control practices. Early efforts focused on the inundative application of individual or mixtures of microbial strains recovered from these systems, and known to function in specific soil suppressiveness. However, the introduction of biological agents into nonnative soil ecosystems typically fails to yield commercially viable or consistent levels of disease control. Of late, greater emphasis has been placed on manipulation of the cropping system to manage resident beneficial rhizosphere microorganisms as a means to suppress soil borne plant pathogens. One such strategy is the cropping of specific plant species or genotypes, or the application of soil amendments with the goal of selectively enhancing disease suppressive microbial communities.

Three essential components are required simultaneously for a disease to occur: a virulent pathogen, a susceptible host and a favorable environment for multiplication often referred to as the 'disease triangle.' Climate change, as well as sometimes fulfilling the last link of that triangle, can also drive evolutionary change in pathogen populations by forcing changes in reproductive behavior (Gregory et al., 2009). One of the most challenging aspects of adapting crops to climate change will be to maintain their genetic resistance to pests and diseases, including herbivorous insects, arthropods, nematodes, fungi, bacteria and viruses. Breeding for host resistance will continue to have a pivotal role in offsetting the adverse impact of climate. Rising temperatures and variations in humidity affect the diversity and responsiveness of agricultural pests and diseases and are likely to lead to new and perhaps unpredictable epidemiologies (Gregory et al., 2009). Factors driving new outbreaks include extraordinary climatic events and trends in temperature selecting pathogens and their natural enemies towards new critical thresholds for inoculums survival. Disease cycle components such as survival, infection, colonization processes and latency period, in addition to production and dispersal of inoculum, are all affected.

Integrated management for controlling potential new disease and pest epidemics are need of the hour. The management methods used for a particular insect or disease problem will depend on the insect species or pathogen involved the extent of the problem, and a variety of other factors specific to the situation and local regulations. Nevertheless, the efficient IPM practice will depend on a thorough knowledge of the pest life cycle, environmental conditions, cultural practices, and minimizing host plant abiotic stresses. A stressed plant grown under drought, saline or water-logged situation is much more susceptible to pest problems.

The need for more expensive control practices of a pest would be required if the problem is permitted to spread. Total elimination of a pest is not always feasible nor is it biologically desirable, if the process is environmentally damaging or leads to new, more resistant pests and eliminates beneficial fungi and insects. IPM uses as many management (control) methods as possible in a systematic program of suppressing pests to a commercially acceptable level, which is a more ecologically sound system.

InIPM better-targeted control with less chemical usage occurs because of the integration of additional biological and cultural management measures. Cultural control begins with the preplant treatment of soil mixes to suppress pathogens and pests. Other cultural control techniques include sanitizing of soil or growing media, not allowing any drought stress, providing good water drainage to reduce the potential of *Phytophthora* root rot and other damping-off organisms, reducing humidity to control *Botrytis*, minimizing the spread of pathogens by quickly disposing of diseased plants from the field. Biological control measures include predator insects and mites; beneficial nematodes and beneficial fungi and bacteria.

Bioinsecticides or biofungicides are preventative, rather than curative, and must be applied or incorporated before disease onset to work properly. Recently, neem (*Azadirachta indica*) products have been found highly effective among several botanicals used for pest control. Pheromone traps are being used to manage fruit flies in mango. Likewise, the beneficial fungus *Gliocladium virens* is an alternative to the chemical fungicide Benomyl. As higher plants have evolved, so have beneficial below-ground organisms interacting with the plant root system (the plant rhizosphere). Examples of this include symbiotic nitrogenfixing bacteria, which are important for leguminous plants, and selected nematodes that control fungal gnats. It is wellknown that beneficial mycorrhizal fungi (which naturally colonize the root systems of most major horticulture plants) can increase plant disease resistance, and helps alleviate plant stress by enhancing the host plant water and nutrient uptake. Mycorrhizae can also benefit propagation of cuttings, seedlings, and transplanting of liner plants. *Tricoderma virde* and *Tricoderma harzianum* have been frequently used in recent years to manage Fusarium wilt in crops. These species have plant growth-enhancing effects, independent of their biocontrol of root pathogens.

These beneficial microorganisms suppress fungal root pathogens by antibiosis (production of antibiotic chemicals), by parasitism (direct attack and killing of pathogen hyphae or spores), or by competing with the pathogen for space or nutrients, sometimes by producing chemicals such as siderophores, which bind nutrients (such as iron) needed by the pathogen for its disease-causing activities. The inhibitory capacity of these biocontrol antagonists increases in the presence of mycorrhizal fungi, and in the absence of plant pathogens there is a stimulation of plant growth by bacterial antagonists; somehow these bacteria stimulate plant growth, but the mechanism is not well known.

1.11 PROTECTED CULTIVATION

The name *'protected cultivation'* involves a series of techniques for the modification of the natural environment of plants, which totally or partially alter the microclimate conditions, with the aim of improving their productive performance. Among the protected cultivation techniques, it is worth noting that mulches, direct covers, net houses, low and high tunnels, glass and polyhouses and microirrigation, mist system, etc., play major roles. The main objectives of protected cultivation are, among others, to protect the crops from harmful temperatures, wind, rain, hail, snow, insect pests, diseases and predators, and creating a favorable microclimate that allows for the improvement in their productivity, product quality and early maturity.

Protected cultivation is thus ideal for the areas, which face frequent fluctuations in weather conditions or experience extreme events like prolonged cold or heat wave or severe droughts or unprecedented heavy rains. Walk-in tunnels are suitable to raise off-season nursery and off-season vegetable cultivation. Insect proof net houses can be used for virus-free cultivation of tomato, chili, sweet pepper and other vegetables particularly during the rainy season. Green houses can be used for high quality vegetable cultivation (Ghosh, 2009).

Greenhouses provide better control over environmental factors affecting plant growth. If environment is controlled, crops can be produced to specific market dates and the quality maintained by eliminating many of the variations and hazards associated with weather and biotic pests. Temperature can be regulated with varying degree of precision, damage from wind and rain is avoided; injury from plant diseases and insects is reduced to a great extent. Growing media, moisture content, and fertility levels can be adjusted to meet plant requirements. However, the precision with which the environment is regulated is determined by the ability of the grower to manage the greenhouses equipments and controls. A profitable operation demands maximum and efficient utilization of greenhouse space. Crop must be mature when demand is greatest. To meet this demand, complete control of the greenhouse environment is essential.

Climate change in the form of temperature rise, a distinct change in the rainfall pattern has already worried farmers in areas where crop production is monsoon dependent. It has also raised questions over the profitability of growing high value crops like roses, gerbera, anthurium, capsicum, tomato, cucumber, etc. under open field conditions. This year droughts in the initial phases and heavy rainfall towards the end disturbed the farming schedule in parts of our country. This has raised the scope of protected farming in our country. Fortunately, some farmers and enthusiasts are already reaping benefits of the system. Protected farming provides distinct advantages with respect to quality, productivity and better market price of the produce. Vegetable and flower growers can increase their income by cultivation of vegetables/flowers during the off-season. The vegetables produced during the normal season generally do not get good returns due to their large availability or glut in the markets. Considering the volatile climate, protected farming is now becoming more relevant to quality production of high value crops, for example, vegetables, flowers and other ornamental crops.

1.11.1 TEMPERATURE CONTROL

A basic reason for using a greenhouse is to control the temperatures at which plants are grown. During the winter months, night temperatures can be maintained at any level with a well-designed heating system and overhead or perforated tube ventilation. Good control is possible in the spring and fall for temperatures equal to or higher than ambient levels. In the summer, however, night temperatures will be higher than outdoor temperatures until the radiant energy absorbed by plants, benches, and walks is dissipated. Heat transfer can be accelerated with exhaust fans. Evaporative cooling, however, is not very effective at night and it raises the relative humidity to levels that favor disease development, particularly Botrytis. Summer night temperatures above ambient levels can be maintained easily if the heating system is in operation.

Day temperature control is an entirely different situation. Although greenhouses are constructed to regulate temperatures, they actually interfere with temperature control. The problem is mainly one of keeping the greenhouse cool. When outdoor temperature are low, it is relatively easy to maintain day temperatures within desired limits. Heat can be added through the heating system or it can be removed by overhead or perforated tube ventilation. As seasonal temperatures increase, however, precise control of day temperatures becomes more difficult. It generally requires forced ventilation or evaporative cooling. In the summer months, acceptable control of day temperatures requires ventilation with roof and side ventilators, use of curtains for roof shading, ventilation with exhaust fans, fan and pad for evaporative cooling, misting and the operation of an evaporative cooling system. Several methods for cooling greenhouses are available. They depend on convection or forced air movement with or without the evaporation of water.

1.12 CONCLUSIONS

Predictions on future climatic conditions indicate possibilities of increases in temperature from 1 to 3 °C by 2050 combined with some complex spatially explicit changes in rainfall. However, there remains high uncertainty in predictions of extreme events, especially hurricanes. Consequently, climate change is likely to invoke substantial changes to production of horticultural crop in a region and the severity with which biotic and abiotic stresses will affect the productivity of these crops. Since climate change can be expected to have varying effects in different areas on the expression of drought, salinity, water logging and pest infestation, the mitigation strategies also vary according to the prevailing situations. While there will be increased irrigation under drought conditions, urgent measures are required for irrigation in drought areas and drainage of water from localities getting excessive rain or flood causing waterlogged situations. New advance technologies can be helpful in offsetting the negative effects of climate change.

Biotechnology can enhance the speed, flexibility and efficiency of developing new cultivars showing resistance to biotic and abiotic stresses arisingdue toimpact of the climate change. Cryopreservation can be adopted for long-term storage of genetic materials. This can eliminate the chances of losing the genotype due to bad weather from the field gene bank. Through micropropagation technique large quantity of high quality, disease free planting materials can be prepared within a stipulated time. The concept of HDP is becoming widespread all over the country. The primary reasons for its adoption have been earlier cropping and higher yields, which translate to higher production efficiency, better utilization of land, and a higher return of investment. This system offers better opportunities than the traditional planting approach. Under changing climatic scenario, drought and salinity are the major and most widespread environmental stresses that substantially constrain crop productivity. Drip irrigation and fertigation systems have been found highly effective and beneficial with a yield gain of 10 to 60% and water saving from 30 to 70% compared to traditional irrigation methods.

Rising temperatures and variations in humidity not only affect the responsiveness of crops to various pests and diseases but are likely to have distinct effects on population thresholds of the insect pests, disease causing pathogens and both beneficial as well as harmful soil microbes. INM and IPM are better solutions for sustainable higher production of crops even in altered climatic conditions. Protected cultivation can be a suitable option to protect the crops from harmful temperatures, wind, rain, hail, snow, insect pests, diseases and predators in the areas, which face frequent fluctuations in weather conditions or experience extreme events like prolonged cold or excessive heat. Advancement in technologies has done fairly well in tackling various abiotic and biotic stress related problems. Tomorrow's horticultural industry will be dominated far more than today's by crop improvement, production, and protection technologies. Research generates technologies and technology generates a series of benefits to the growers. Thus, tomorrow's growers would be far more well versed in