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Kodthalu Seetharamaiah Shivashankara
Editors

Climate-Resilient Horticulture: Adaptation and Mitigation Strategies

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Foreword

I am happy that our scientists have started taking anticipatory action to checkmate the adverse impact of climate change. India is in the midst of a horticultural revolution. Already we are producing over 250 million tonnes of fruits and vegetables. We will probably produce over 350 million tonnes of horticultural products by 2020. This should have a good impact both on farmers' income and consumers' nutrition security.

The areas which need anticipatory research are increase in mean temperature, adverse changes in precipitation leading to the more frequent occurrence of drought and flood and the rise in sea level affecting adversely the coastal agriculture and horticulture. Along the coast, coconut and cashew nut grow well. We will have to analyse crop by crop the potential impact of climate change on their productivity, profitability and sustainability. There is also a need for participatory research with farmers in order to develop and implement drought and flood codes. Both adaptation and mitigation strategies will have to be popularised. I wish to congratulate the Confederation of Horticulture Association of India on their initiative in compiling very useful information in the form of a book titled "Climate-resilient horticulture: adoption and mitigation strategies".

Climate change will be a mega catastrophe. On the other hand, every calamity also opens up opportunities to checkmate genetically and agronomically potential adverse situations. I thank Dr. H P Singh for his vision in getting such a book published. I hope the book will be widely read and used by professionals, policy makers, farmers, university scholars and the public.

Research Foundation, Third Cross Street,
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M.S. Swaminathan

Preface

Climate change, a global phenomenon, is a concern for food and nutritional security of growing population, expected to be 9.5 billion at the end of 2050, and has attracted global, regional and national dialogues for mitigation and adoption strategies. The likely effects stipulated are occurrence of drought and floods, change in rainfall pattern and sudden change in temperatures, which will have impact on the growth pattern of plant, flowering, fruiting and yield and quality of produce, besides increasing vulnerabilities to pest and diseases. How to handle the challenges of climate change in terms of adaptation and mitigation strategies is a point of discussion in the programmes of the governments, globally. Adaptive mechanisms through the development of new crops, cultivars and technologies are also a priority research agenda for most of the research organisations. Since impact of climate change will largely depend on current agro-climatic conditions, cropping pattern and socio-economic conditions, solution to the problems arising out of it requires local analysis, planning and management. Horticulture, along with wide arrays of crops, may have differential responses: some may benefit from higher amount of carbon dioxide, while flowering and fruiting may not occur; some crops may extend in area due to less occurrence of frost, while some crops may shift from mid hills to upper hills. Therefore, understanding the impacts in a given crop under specific situation becomes inevitable in horticulture as most of the horticultural crops are long duration or perennial in nature. This necessitates a thorough analysis and understanding about climate change at regional levels in relation to both annual and perennial horticultural crops, which could be managed through innovation, technology evaluation and refinement to provide effective solutions. Methodologies for analysis in many crops are now available. Mathematical models have been developed using available basic data on the crop response to different climatic factors, which have the potential to predict likely impact as well as suggest ways to overcome the problems to some extent, suggesting that impact will differ from region to region, depending upon current ecological and climatic conditions. With a rise in temperature, shifting of apple-growing areas, altering of phenological stages of fruit trees and changing of quality of horticultural produce with respect to carotenoids and anthocyanins are taking place. Growth stages are shortening, leading to early maturity and reduction in yield. Evidences also suggest that with a rise in carbon dioxide concentration, there could be an enhanced photosynthesis and ultimately higher biological yield, provided water and nutrients are managed effectively. However, increase in temperature may alter the photosynthate partitioning and phenology of flowering, and new pathogens and insect pests may emerge. Development of high-temperature tolerant cultivars, change in production systems and use of new tools and technology would help in adaption to climate change.

The potential of perennial fruit and plantation crops for higher carbon sequestration provides an opportunity to be a sink for increased carbon dioxide and, additionally, opportunity for soil carbon sequestration. Interior and exterior landscape gardening has proven benefit in reducing carbon concentration. Taking stock of current knowledge about the effect of climate variables and their synthesis for new knowledge in relation to climate change is imperative for adaptive strategies. Accordingly, analysis was made in a series of expert consultations and national dialogues, which enhanced the knowledge about impact of climate change on horticultural crops and also provided guidance to adoptive strategies for different crops in many ago-climatic conditions. The present book, Climate-Resilient Horticulture: Adaptive and Mitigation Strategies, is a treasure of knowledge on horticultural crops, contributed by experts in the field. The book contains chapters covering impact analysis for the regions and crops. The chapters also cover impact on pollinators, pests and diseases and landscape gardening for climate change mitigation. We are sure that this book will be a major source of information for all concerned with climate change in horticulture.

We take this opportunity to express our gratitude to Dr. S. Ayyappan, Secretary, Department of Agricultural Research and Education, and Director General, Indian Council of Agricultural Research, New Delhi, India, for his guidance and support. Our thanks are extended to all the contributors for their inputs and timely submission of the chapters. Thanks are due to Mrs. Shobha Rani for secretarial assistance and Mrs. Hema Malini and Mrs. Malarvizhi for their assistance in the compilation of the information. Review of manuscript by Dr. Babita Singh, Professor of Horticulture, Amity University, is thankfully acknowledged. We are also grateful to all those who helped, directly or indirectly, in bringing out this valuable book.

H.P. Singh, N.K. Srinivasa Rao,
and K.S. Shivashankara

About the Editors

Dr. Harish Chandra Prasad Singh, with his rare combination of scientific excellence, conscientious administration, dynamic management skills and academic depth, in the career spanning 41 years, has outstandingly contributed to research, development and academics. Dynamic leadership of Dr. Singh has earned him national and international recognitions. He is the recipient of three international and 35 national awards and nine fellowships, including the fellowship of National Academy of Agricultural Sciences. He has provided a new dimension to horticultural research and development and human resources, leading to horticulture revolution in the country. His visionary approach with zeal and commitment for achieving excellence and exemplary skill of management has brought dynamisms to the positions that he held (Deputy Director General (Hort.), ICAR (2007–2012); Vice-Chancellor, RAU, Pusa, Bihar (2005–2007); Dean, College of Agriculture, GBPUA&T, Pantnagar (2004–2005); Horticulture Commissioner, Ministry of Agriculture (1997–2003); Chairman, Coconut Development Board, Cochin; Director, National Research Centre on Banana, Trichy (1993–1997); and Project Coordinator (fruits), IIHR, Bangalore), leading to optimisation of output, outcome and delivery. Dr. Singh has also provided international leaderships as chairman of international organisations as well as committees. He is affiliated with many professional associations/societies as chairman, president, vice-president and general secretary. He has authored and edited 57 books, 30 bulletins, 50 reports and more than 300 scientific papers. He is the editor-in-chief of International Journal of Innovative Horticulture, published by CHAI. He has widely travelled in India and abroad, has been a keynote speaker in international and national conferences and has organising capacity par excellence. Currently, he is the founder and chairman of Confederation of Horticulture Associations of India (CHAI).

Dr. Nadipynayakanahally Krishnamurthy Srinivasa Rao, ex Principal Scientist (Plant Physiology) and emeritus scientist, belongs to the first batch of Agricultural Research Service. He has passed ARS examination with the first rank and then joined ICAR service in 1976 at Indian Institute of Horticultural Research, Bangalore. He has contributed significantly to the understanding of the mechanism of abiotic stress tolerance in horticultural crops. He was associated with the release of one important tomato variety Arka Meghali, recommended for cultivation under rainfed conditions, with the breeding of tomato and onion for water stress and with capsicum, French bean and peas for high-temperature tolerance. He has significantly contributed in identifying genotypes tolerant to abiotic stresses, and the same has been used by the vegetable breeders for breeding varieties for water and high-temperature stress conditions.

Dr. Rao was the chairman of the group for the discussion and preparation of a work plan for South Asian countries on management of heat, moisture and other plant stresses under SAVERNET at the Joint Planning Meeting held at the Bangladesh Agricultural Research Council, Dhaka, Bangladesh, from 24–27 February 1992. IIHR has been identified as a core institute for research work on horticultural crops under National Initiative on Climate Resilient Agriculture (NICRA). He was the principal investigator of the NICRA project. He has been instrumental in the planning of various programmes on horticultural crops under NICRA. He was also the PI of ICAR Network Project on Impact, Adaptation and Vulnerability of Indian Agriculture to Climate Change since the inception of the project. He has developed a good laboratory for climate change research at IIHR, Bangalore. He devotes his full time in planning and developing these facilities like Free-Air Temperature Enhancement (FATE), Climate-Controlled Greenhouse (CTGC) and Phenomic Platform, which are of national importance. As a senior faculty member, he had the opportunity of visiting facilities for studies on Climate-Resilient Agriculture, CO2 Enrichment and Free-Air Temperature Enrichment facilities at the Department of Horticulture, Cornell University and Brookhaven National Laboratory, Long Island, New York. He has published more than 60 scientific papers in national and international journals, and he has 7 book chapters to his credit.

Dr. Kodthalu Seetharamaiah Shivashankara is a Principal Scientist in the Division of Plant Physiology and Biochemistry at Indian Institute of Horticultural Research, Bangalore. He has got more than 20 years of research experience in various fields like fruit aroma, fruit and vegetable antioxidant phytonutrients, mango-flowering physiology and ripening and storage disorders of fruits and effect of climate change on fruit and vegetable quality. Dr. Shivashankara has more than 30 research articles in various peer-reviewed national and international journals. He has the experience of working in international laboratories like food engineering lab of NFRI, Tsukuba, Japan, and at Lethbridge Research Centre of Agriculture and Agri-Food Canada at Lethbridge, Canada, in the area of antioxidant phytonutrients and fruit volatile flavours. He has been awarded the Fellow of International College of Nutrition, by the International College of Nutrition, Alberta, Canada. Dr. Shivashankara has been training many researchers and guiding students in the area of fruit and vegetable quality as affected by varieties, storage conditions and environmental factors. He has identified many indigenous fruits with high antioxidant capacity. He was also involved in the evaluation and selection of high antioxidant lines in many vegetables.

About the Book

Climate change, a global phenomenon, has attracted scientists to contribute in anticipatory research to mitigate adverse impacts, which are more important for horticulture, considering that the scenario is in the midst of revolution, reaching the production level of 250 million tonnes in India. Impacts of climate variability have, invariably, profound influence on production and quality. An understanding of the impacts and relevant adaptation strategies is of foremost importance to sustain the productivity and profitability of horticulture crops in the climate change scenario, which necessitates synthesis of current knowledge to develop strategies for adaptation and mitigation to achieve climate-resilient horticulture. The book Climate-Resilient Horticulture: Adaptation and Mitigation Strategies addresses the effects of climate change on different horticultural crops and focuses on the adaptation strategies based on the scientific knowledge generated by the experts in different agro-climatic regions in India. Issues have been covered in various chapters to make this book a treasure of knowledge in horticulture vis-a-vis climate change. Some of the crops included in the book are apple, grapes, cashew, banana, litchi, mango, coconut, oil palm, potato, tomato, cucurbits and flowers. In addition to strategies to be adapted in these crops, various other important aspects like carbon sequestration, pests and diseases and urban landscaping are also covered in the book. Information on climatic risks and adaptation options for resilience in horticultural crops and future strategies and information on pest and disease dynamics on horticultural crops in relation to climate change and available mitigation strategies have also been documented. The book is edited by Dr. H P Singh, a visionary leader, and his colleagues, which will be highly valuable to research workers, students, policy planners and farmers to understand and checkmate the adverse effect of climate change, so as to convert weakness into opportunity.

Acknowledgements

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Adaptation and Mitigation Strategies for Climate-Resilient Horticulture

1

Dr. Harish Chandra Prasad Singh

Abstract

The growth of horticulture, as seen in India, has been in 5 phases, which started with a share of 5% GDP of agriculture to 30.4% now. Due to climate change, it is projected that rainfall over India will increase by 15–40%, and the mean annual temperature will increase by 3–6°C by the end of twenty-first century. Shift in varietal choice may become necessary in case of grapevines, banana, mango and other important horticultural crops. Moisture stress has been addressed through the development of varieties tolerant to drought and rainfed conditions. Delaying the date of planting can be an adaptation strategy in most of the states of the Indo-Gangetic plains to minimize the yield reductions while for West Bengal and *Kharif* potato-growing regions development of heat tolerant varieties should be the main adaptation strategy. Dogridge (*Vitis Champini*) has been found promising for improvement in vigour, yield and quality of seedless grapes as well as tolerance to drought and salinity. The number of disease epidemics has dramatically increased in recent years and also the threat of emerging new diseases and the re-emergence of other diseases. Some recent examples are incidence of thrips-transmitted tospoviruses and whitefly-transmitted begomoviruses in chilli, cucurbits, okra and tomato. Hence, there is a need to thoroughly understand the potential climate change impacts on host–pathogen interactions, in order to evaluate appropriate disease management strategies. Horticulture-based farming systems have high potential for sequestering carbon for mitigation of climate change. The perennial trees act as carbon sinks by sequestering the atmospheric carbon. Availability and development of good simulation models for horticultural fruit and vegetable crops is lacking in India probably with

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exception of potato and coconut where InfoCrop model has been adopted and validated for different agro-ecological regions. For adaptation strategies the emphasis should be on development of production systems for improved water-use efficiency and to adapt to the hot and dry conditions. Strategies like changing, sowing or planting dates, modifying fertilizer application, providing irrigation during critical stages of the crop growth and conservation of soil moisture reserves by mulching with crop residues and plastic mulches are the most important interventions. Development of climate-resilient horticultural crops which are tolerant to high temperature, moisture stress, salinity and climate proofing through genomics and biotechnology would be essentially required.

1.1 Introduction

Indian agriculture has made a rapid stride in achieving self-sufficiency in food. Horticulture has emerged as a best option for diversification to meet the need for food, nutrition, health care besides providing better returns on farm land and better opportunity for employment. Little investment made in horticulture has been rewarding in terms of increased production, productivity and export and emergence of India as second largest producer of fruits and vegetables. This changing scenario is attributed to technological interventions and efforts for development. However, the challenges before us are much greater than before and have to be addressed with strategic approaches utilizing innovations in science and technology. Past achievements are testimony for our success in addressing the challenges, which may need investment and concerted efforts in integrated manner.

1.2 Dynamics of Indian Horticulture

The horticulture in India has moved from rural confine to commercial production in last decades, passing through various phases of growth. The growth of horticulture, as seen in India, has been in 5 phases, which started with a share of 5% GDP of agriculture to 30.4% now. The first phase of horticulture (pre-independence) was confined to houses and personal gardens for pleasure, while the second phase (1948–1980) became a commercial production system and few commodities, namely, potato, coconut, areca nut and spices, received attention and institutional support system was established. Recognizing the role of horticulture in nutritional security, employment generation and enhancing the farm income, with added focus third phase (1980–1992) of development, took place, which got the fillip with consolidation of institutional support for research and development. In the fourth phase (1993–2000), the focused attention was given to horticulture with enhancement of plan allocation and strong institutional support for research and development. Initiatives were taken for mission-mode approach and adoption of newer technologies. The fifth phase (2001–2010) is characterized as a phase of innovations and large-scale adoption of technologies like micro-irrigation, micropropagation, protected cultivation and use of in vitro propagated plants and diagnostics resulting in an accelerated growth.

The technology-led horticulture during different phases of growth has shown impressive impact on production, productivity and profitability of all horticultural crops. The production of horticultural produce has jumped eight times from the level of production during 1950–1951. At present, the total production of horticultural produce is 234.5 million t from the 11% of the total cultivated area in India, which contributes 30.4% in value term to GDP of agriculture, and the trend of development has been marked as

"Golden Revolution". But there is a growing demand for horticultural produce both in domestic and overseas markets, and, at the same time, competition is also increasing. During the last two decades, the production of horticultural produce has increased manifold, but the gap in demand and supply continues. However, with declining land and water and with a threat of climate change, there is rising concern for meeting the growing requirement.

1.3 An Insight About Climate Change

Significant variation in either mean state of climate or its variability, persisting for an extended period (typically decades or longer), is referred as climate change, which may be due to natural internal processes or external forcing, or to persistent anthropogenic changes in the composition of the atmosphere or in land use. The earth is the only planet in our solar system that supports life because of unique environmental conditions that are present—water, an oxygen-rich atmosphere and a suitable surface temperature. It has an atmosphere of proper depth and chemical composition. About 30% of incoming energy from the sun is reflected back to space, while the rest reaches the earth, warming the air, oceans and land, maintaining an average surface temperature of about 15°C. The chemical concentration in atmosphere for nitrogen is 78%; about 21% is oxygen, which all animals need to survive; and only a small (0.036%) proportion is made up of carbon dioxide which plants use for photosynthesis. In atmosphere, energy is absorbed by the land, seas, mountains, etc., and simultaneously released in the form of infrared waves. All this released heat is not lost to space, but is partly absorbed by some gases present in very small quantities in atmosphere, called greenhouse gases consisting of carbon dioxide, methane, nitrous oxide, water vapour, ozone and a few others. Thus, increased concentration of greenhouse gases leads to increased temperature which in turn has impact on the world climate, leading to the phenomena known as climate change. The earth's climate system constantly adjusts so as to maintain the balance between the energy that reaches it from the sun and the energy that goes from earth back to space. This means that even a small rise in temperature could mean accompanying changes in cloud cover and wind patterns. Some of these changes may enhance the warming, while others may counteract. Cooling effect may result from an increase in the levels of aerosols (small particles of matter or liquid that can be produced by natural or man-made activities). Positive feedback may result from an increase in water vapour due to high evaporation with rise in temperature and can further add to the warming effect. The significant change may impact agriculture/horticulture/fish/livestock and consequently food supply. Climate change per se is not necessarily harmful, but the problems arise from extreme events that are difficult to predict, like more erratic rainfall pattern and unpredicted warm spells shall affect productivity. At the same time, more availability of CO_2 would help in improved yield of root crops, and increased temperature may shorten the period.

1.4 Climate Change in Asia

The increase in temperature due to global warming is 0.76°C since 1850. The rate of warming in the last 50 years is double than that for the last century. As many as 11 of the past 12 years were warmest since 1850, when records began. The likely increase in temperature is 1.8–4°C by next century (IPCC 2007). The threshold value of temperature rise is 2°C for devastating, dangerous and irreversible consequences of warming to manifest world over. Global warming is occurring along with shifting pattern of rainfall and increasing incident of extreme weather events like floods, droughts and frosting. Recent studies suggest clear evidence of reduction in light intensity, rapid melting of glaciers and rise in sea level. The estimates of Indian Institute of Tropical Meteorology, Pune, indicate similar trends in India with slightly higher magnitude. It is projected that rainfall over India will increase by 15–40%, and the mean annual temperature will increase by 3–6°C by the end of twenty-first century. Warming is likely to be more pronounced over land areas with the maximum increase over northern India. The winter and post-monsoon seasons are likely to be more affected by warming. Besides, there would be more fluctuation in temperature, and water availability may decline.

The South Asian region is projected to be one of the most vulnerable to climate change. It is attributed to increasing population pressure, extreme poverty and predominance of agriculture and resource crunch in the region. It is projected that by 2020, food requirement in South Asia would be 50% more than the current demand. The challenge is to produce the same from constant or even shrinking land resources due to competition for land from other sectors like infrastructure, industry and housing. Poverty alleviation and food security for teeming millions in India under adverse climate change scenario would be a daunting task. These changes in global environment will have profound effects and serious consequences for agriculture, horticulture, arable ecosystem and society as a whole.

1.4.1 Likely Impact of Climate Change

Global climate change is expected to affect agricultural/horticultural crops through its direct and indirect effects. Scientific evidence suggests a positive effect of increase in atmospheric carbon dioxide in C_3 photosynthetic pathway promoting their growth and productivity. Increased CO_2 will reduce evapotranspiration and thus increase water-use efficiency. However, positive effects will be counteracted by increase in temperatures. Rise in temperature will reduce crop duration; increase respiration rate; alter photosynthate partitioning to economic product; alter phenology, particularly flowering, fruiting and reducing chilling unit accumulation; and hasten senescence, fruit ripening and maturity. Cauli-flower grows best in cool to warm conditions (15–25°C) with high humidity. Though, some varieties can grow with temperatures over 30°C, but most of the varieties are sensitive to higher temperature. Delayed curd initiation in cauliflower is reported due to increased temperature. Tem-perature above 30°C induces maximum flower and fruit drop, and high temperatures after pollen release decrease fruit setting, fruit yield and seed setting in tomato.

The sensitivity of individual crop to temperature depends on inherent tolerance and growing habits. Indeterminate crops are less sensitive to periods of heat stress because the time of flowering is extended compared with determinate crops. In onion, warmer temperatures shorten the duration of growth, leading to lower crop yields. Any soil warming would be advantageous for cucurbits, which are generally direct seeded and have a high heat requirement. The rise in temperature will influence survival and distribution of pest population; develop new equilibrium between alternate host crops and pests, hasten nutrient mineralization in soils, decrease fertilizer-use efficiency and increase evapotranspiration with reduced water-use efficiency. The net effect of climate change on horticultural crops will depend on interaction effects of rise in temperature and CO_2 concentration in atmosphere. In general, CO_2 enrichment does not appear to compensate for the detrimental effects of higher temperature on yield. Most importantly, the quality of produce of these horticultural crops is likely to be impacted severely.

1.4.2 Changing Pattern of Cropping System

Many slow-growing fruit crops require heavy investment on establishment of orchards. Quick alteration/shifting of fruit species or varieties would be difficult and painful loss-bearing exercise under the impact of climate change, which may discourage the development. Recent studies have indicated that in Kullu district of Himachal Pradesh, farmers shifted from apple to vegetables, while in Shimla district at relatively higher altitude, orchards have been replaced from high-chilling requiring apple cultivars of apple (Royal Delicious) to low-chilling requiring cultivars and other fruit crops like kiwi, pomegranate and vegetables. In mid-hills of Shimla district, trend is to shift from apple and potato cultivation totally. It is corroborated by declining trend in snowfall and apple productivity in Himachal Pradesh. The mean productivity of apple in 1980–1981 was 7.06 t/ha compared to 4.65 t/ha in 2004–2005. Since many crops with chilling requi-rements are tree species, moving production areas is difficult. Thus, in replanting orchards and plantations over the next decade, selection of low-chilling requiring types may be advisable. This is just an example of impending impacts of global warming and climate change.

Grape being a temperate crop has very well adapted to tropical regions; under climate change scenario with increase in temperature, there would be change in growing degree days (GDD), which has direct bearing on phenology of the crop (Singh 2010). Hence, under such circumstances, we would have to identify varieties and regions suitable for production of quality fruits. Shift in varietal choice may become necessary in case of grapevines, banana, mango and other important horticultural crops. With global warming, production areas for specific crops and/or timing of planting could be changed, but for many horticultural crops, market windows and infrastructure, such as availability of local packing and distribution facilities, are critical components of the production system. Locations of important production areas are often defined as much by available land, markets and infrastructure as by climatic conditions per se. Thus, as horticulturists we have to ask ourselves and our clientele whether it is realistic to move production areas in response to climate change or whether there are other production practices that can be adjusted to compensate climate change. Climate change and CO_2 are likely to alter important interactions between horticultural plants and pollinators, insect and disease and pests and weeds.

1.5 Current Status of Impact and Adaptation Studies in Horticultural Crops

1.5.1 Vegetables

Shallow-rooted vegetables are known to be sensitive to moisture deficiency and require frequent supply water of for better yield and quality. Studies have indicated that soil water stress at early stages of onion crop growth caused 26% yield loss. In tomato, water stress accompanied by temperatures above 28°C induced about 30–45% flower drop in different cultivars (Srinivasa Rao 1995). Chilli, with 60% area under rainfed cultivation, also suffers drought stress, leading to yield loss up to 50–60%. Most vegetables are sensitive to excess moisture stress conditions due to reduction in oxygen in the root zone. Tomato plants under flooding conditions accumulate endogenous ethylene, leading to rapid epinastic leaf response. Onion is also sensitive to flooding during bulbing with yield loss up to 30–40%. Moisture stress has been addressed through the development of varieties tolerant to drought and rainfed conditions, for example, Arka Vikas in tomato, Arka Kalyan in Onion and Arka Lohit in Chilli. Some advanced lines identified having drought tolerance are IIHR Sel. 132 in Chilli, RF-4A in tomato, MST 42 and MST 46 in onion (Anonymous 2011). The production technologies like integrated nutrient management practices and in situ soil conservation and polythene mulching have been developed for rainfed chilli production.

In tomato, high temperatures can cause significant losses in productivity due to reduced fruit set, smaller size and low-quality fruits. Optimum daily mean temperature for fruit set in tomato has been reported to be 21–24°C (Geisenberg and Stewart 1986). The pre-anthesis stage is more sensitive in tomato. Post-pollination exposure to high temperature inhibits fruit set in pepper, indicating sensitivity of fertilization process. In cucumber, sex expression is affected by temperature. Low temperatures favour female flower production, which is desirable, and high temperatures lead to production of more male flowers. The duration of onion gets shortened due to high temperature, leading to reduced yields. Though cauliflower is a temperate crop, with development of tropical Indian cauliflower, it became possible to cultivate in hot and humid tropical conditions and throughout the year in north Indian plains. Now, India is second highest producer after China with a share of 33% of the world production.

We have attained productivity levels of 19.0 t/ha, which is higher than the world average of 17.3 t/ha. Though some varieties have adapted to temperatures over 30°C, most varieties are sensitive to higher temperatures, leading to delayed curd initiation.

In Karnataka, Maharashtra and in plateau areas of Madhya Pradesh, Jharkhand and Orissa where *Kharif* crop is taken, the temperature constraint is primarily due to high night temperatures, which are already bordering the critical temperature for tuber initiation and good bulking. Preliminary simulation studies indicate reductions in productivity from 6% to 18% in the different states are likely by 2020 if no adaptation strategy is adopted. Studies indicate that delaying the date of planting can be an adaptation strategy in most of the states of the Indo-Gangetic plains to minimize the yield reductions, while for West Bengal and *Kharif* potato growing regions, development of heat-tolerant varieties should be the main adaptation strategy.

1.5.2 Tuber Crops

In India, potato is grown in a thermally suitable window, and the availability of suitable growing period in India is likely to be affected seriously by climate change. The heat-sensitive potato crop is mostly confined to Indo-Gangetic plains (about 80% of the area) under irrigated conditions due to climatic constraints. Higher temperature at the start of the growing season would lead to shortening of the effective growing season. The preliminary results of the simulations studies show that the productivity is likely to improve in Punjab, Haryana and Western UP by 7% and 4% in the year 2020 and 2050, respectively (Singh et al. 2005 and 2008). In these areas, currently the growing period is short due to the occurrence of frost and due to the warming up of winters, frost situations may become infrequent and consequently longer growing period could be realized, leading to improved productivity. In states like Bihar, West Bengal Gujarat, the productivity is likely to decrease by 2–19% and 9–55% in the year 2020 and 2050, respectively, since in these areas, the winters are already milder and further rise in winter temperatures would adversely affect the productivity (Singh et al. 2010).

Although cassava and sweet potato are considered to be tolerant to drought conditions, significant reduction in tuber yield as well as in starch content occurs, and varieties vary in their response to water-deficit stress/high-temperature stress conditions. Mild water-deficit stress (WDS) is favourable for tuber growth. In cassava, drought during first 3 months delays tuber initiation and bulking. Studies have shown that about 28–42% of tuber yield was found to be reduced under drought conditions during last 4 months of crop growth period (Ramanujam 1990). Sweet potato yields decreased when the available soil moisture decreases below 20%, and the tuber initiation period is the most sensitive to due to its effect on tuber number. Water stress during tuber initiation period induces lignification of tubers and hampers tuber growth. Sweet potato variety "Sree Bhadra" tolerant to drought conditions has been released by Central Tuber Crops Research Institute, Trivandrum. Although cassava may sustain vegetative growth and biomass at high temperatures (33–40°C) under adequate soil moisture, sucrose synthesis and export from the leaves and starch synthesis in tubers will be affected at temperatures >30°C. Simulation studies at CTCRI on increase in temperature on sweet potato yield using SPOTCOMS model showed that tuber yield increased by 1.26 t/ha due to 1°C rise in mean temperature between 19.24°C and 20.24°C and yield decreased by 0.12 t/ha due to 1°C rise in mean temperature between 28.24°C and 29.24°C.

1.5.3 Fruit Crops

Perennial fruit crop orchards are established with large investments; the stresses imposed due to climate variability would influence the production on year-to-year basis, influencing the farmers' income drastically and his decision to continue growing such crops in the long run. Continuous losses for few years would force the farmers to give up growing such crops altogether. In Himachal Pradesh, the rise in average temperature, long spells of drought during summers and less snowfall during winters have rendered large area supposed to be marginally suitable for apple cultivation unfit, thereby forcing farmers to shift to cultivation of other cash crops. Apple cultivation has been adversely affected in lower areas of Kullu and Mandi districts, and as a result of this, the farmers in the state have shifted to cultivation of vegetables like tomato and peas. In Rajgarh area of Sirmaur district, apple area has been diverted to peach.

Mango has vegetative bias, and this becomes stronger with increase in temperature, thus influencing the flowering phenology. Temperature is reported to have influence on flowering, and the percentage of hermaphrodite flowers was greater in late emerging panicles, which coincided with higher temperatures (Singh et al. 1966). The extreme weather events of hot and cold wave conditions have been reported to cause considerable damage to mango and guava. Delay in monsoon, dry spells and untimely rains during water stress period imposed for inducing flowering, higher temperatures during flowering and fruit growth are most commonly encountered climatic conditions by the citrus crop. Higher temperature (31–32°C), in general, increases the rate of plant maturity in banana, thus shortening the bunch development period (Turner et al. 2007). High air temperatures (usually greater than 38°C) and bright sunshine cause sunburn damage on exposed fruits. Choking of bunches is also caused by high temperatures (above 38°C) and drought (Stover and Simmonds 1972). The soil moisture deficit stress in banana during vegetative stage causes poor bunch formation, lower number and small-sized fingers. Waters stress during flowering causes poor filling of fingers and unmarketable bunches. Water stress reduces the bunch weight and other growth parameters. Bananas subject to flooding by stagnant water for more than 48 h are severely stunted. Though grape originated in temperate regions, modifications in production system, taking up two prunings and one crop, have enabled it to adapt to tropical conditions. Under climate change conditions there would be changes in availability of growing degree days (GDD), leading to hastening of the phenological processes. Dogridge (*Vitis champini*) has been found promising for improvement in vigour, yield and quality of seedless grapes as well as tolerance to drought and salinity.

1.5.4 Plantation and Spice Crops

Cashew requires relatively dry and mild winter coupled with moderate dew during night for profuse flowering. High temperature (>34.4°C) and low relative humidity of <20% during afternoon cause drying of flowers, resulting in yield reduction. Cashew, being grown mostly under rainfed conditions, is vulnerable to climatic variability and drought conditions caused due to shifts in rainfall pattern. Unseasonal rains and heavy dew during flowering and fruiting period aggravate the incidence of pests and diseases, and pollinating insect activities also reduced to the minimum resulting in poor setting of nuts. Further the rains received during harvesting period result in soaking of nuts and affecting shelf life of nuts and quality of kernels. Unseasonal rains at ripening stage lead to blackening of nuts as well as rotting of apples on trees (Yadukumar et al. 2010).

The studies conducted at Central Plantation Crops Research Institute, Kasaragod, indicate the general warming trend is in most of the coconut growing areas (Naresh Kumar et al. 2007). Coconut productivity increased over the past 50 years except recent declining trend in Maidan area of Karnataka, Coimbatore of Tamil Nadu state, due to consecutive droughts. The production was reduced by about 3,00,000 nuts/year for 4 years. Productivity loss was to the tune of about 3500 nuts/ha/year. Apart from drought, other natural calamities like cyclone have impacted the crop production and productivity. For instance, the decline in crop production due to1996 cyclone in Godavari district of Andhra Pradesh was to the tune of 220 million nuts/year in 6 years. Climate projections in different scenarios indicated that Maidan parts of Karnataka, eastern Tamil Nadu, coastal Andhra Pradesh, Pondicherry, West Bengal and Assam in decreasing order are found to be hot spots as per different HadCM3 model scenarios.

The spice crops generally grown as intercrop in plantation crops are also equally influenced by climate change. Studies have shown that many suitable areas of spices will become marginally suitable, or new areas, which are presently unsuitable, become highly suitable for cultivation of spices. Geographic information system (GIS) was used at Indian Institute of Spices Research, Calicut, to analyse the effect of change in the climatic parameters on black pepper and ginger. The Eco-crop model of DIVA GIS indicated that with an increase of 2°C, most of the areas where these crops are being cultivated may become unsuitable and some new areas may become suitable for cultivation (Krishnamurthy et al. 2010). Seed spices are winter season crops and commonly grown in arid and semi-arid track of Rajasthan and Gujarat, requiring certain period of low temperature for optimum vegetative growth.

The arid zone ecosystem is very fragile and is prone to serious imbalances even with the slightest disturbance. Drought is a recurrent phenomenon in arid region, and among abiotic stresses, water stress and occurrence of low temperature during critical growth stage affect seed spices.

1.6 Impact of Climate Change on Outbreak of Diseases and Pests

Studies have indicated that under climate change conditions, elevated carbon dioxide concentrations, altered temperature and precipitation regimes may alter growth stages and rates of development in the life cycle and pathogenicity of pathogens, as well as modify the physiology and resistance of host plants. Based on assessment of important diseases of horticultural crops in India, impacts of climate change are felt in epidemic out breaks of fruit rot (*Phytophthora meadii*) and leaf spot (*Phyllosticta arecae* and *C. gloeosporioides*) of areca nut, bud rot (*Phytophthora palmivora*) of coconut, yellow rust, *Alternaria* bunch rot, *Botryodiplodia* dieback and *Grenaria* leaf and fruit rot in grapes, *Macrophoma* in banana, *Cercospora* and wilt in chillies, blossom blight in mango and wilt and nodal blight in pomegranate in certain locations. Although Phytophthora blight was a serious limiting factor in potato in India since 1952, these diseases never posed any threat to other vegetable crops. Since 2008, severe outbreaks of Phytophthora diseases such as late blight on potato and tomato (*P. infestans*), fruit rot on brinjal (*P. parasitica*), wilts in chilli and capsicum (*P. capsici*), blights in cucurbits (*P. capsici*), fruit rot in okra (*P. parasitica*) and root rot in cabbage and cauliflower (*P. megasperma*/*P. drechsleri*) have been noticed (Chowdappa 2010).

The detailed analyses of *P. infestans* populations associated with late blight of tomato indicated emergence of new population that differed from the "old" US-1 lineage that dominated the *P. infestans* population worldwide prior to 1980 and IN-1 and IN-2 genotypes on potato in India. This new population triggered severe epidemics on tomato in India since 2009. As result, 10–15 fungicide applications from as early as June through October are taken in Karnataka state to manage late blight on tomato. This causes a significant expenditure to farmers and a significant environmental risk. Studies elsewhere have predicted that for each 1 °C increase in temperature, late blight can occur 4–7 days earlier, and the susceptibility period extended by 10–20 days. The incidence of Sigatoka leaf spot disease was first reported by the All India Coordinated Research Project (tropical fruits) Jalgaon Centre during the year 1997–1998. As a case study the relationship between the weather parameters (2000–2007) and the incidence of Sigatoka leaf spot disease clearly shows a positive correlation with an increasing trend in the afternoon relative humidity and the increase in rainfall over the corresponding years.

Changing climate conditions can contribute to a successful spread of newly introduced viruses or their vectors and establishment of these organisms in areas that were previously unfavourable. For example, tobacco streak virus was introduced in India in 1997, and now it is adapted to chilli, cucurbits, ornamentals and okra. The most important vectors such as aphid, whitefly, thrip and leaf-hoppers, which are associated with potyviruses, begomoviruses, tospoviruses and phytoplasma, have emerged during the last two decades. Recent observations have shown that resistance to Bhendi yellow vein mosaic virus tends to break when okra is grown at higher temperatures. The number of disease epidemics has dramatically increased in recent years and also the threat of emerging new diseases and the re-emergence of other diseases. Some recent examples are incidence of thrips-transmitted tospoviruses and whitefly-transmitted begomoviruses in chilli, cucurbits, okra and tomato. Hence, there is a need to thoroughly understand the potential climate change impacts on host–pathogen interactions, in order to evaluate appropriate disease management strategies (Krishna Reddy 2010).

1.7 Modelling to Predict the Likely Impact of Climate Change

We need quick and clear understanding of impact of climate change on horticultural crops for making sound action plan because horticulture-based farming systems have high potential for sequestering carbon for mitigation of climate change. The perennial trees act as carbon sinks by sequestering the atmospheric carbon. The carbon credits could be earned under the clean development mechanism (CDM). The horticultural waste could be composted locally instead of dumping in the landfills, which can reduce the release of methane that is involved in global warming. The organic waste could also be used for generating biogas as an alternate energy source. There are considerable uncertainties about agronomic implications of horticultural crops. Predicting impact of climate change on horticultural crops accurately on regional scale is a big problem. It can be accomplished only by a modelling approach through well-validated robust crop simulation models. These crop simulation models incorporate the effect of various factors of growth and yield in a mathematical model processed by computers to give results quickly for specific situation. Well-validated simulation tools developed for cereal crops have been helpful in predicting of impact of climate change. Availability and development of good simulation models for horticultural fruit and vegetable crops are lacking in India probably with exception of potato and coconut where InfoCrop model has been adopted and validated for different agro-ecological regions. Controlled experiments for perennial crops with large-size trees are difficult for quantifying the direct effect of various abiotic stresses on growth, development and yield. We need to develop methodologies to quantify the adverse impacts of climate change on perennial crops like mango, grapes, apple, orange, citrus, litchi, guava and others on priority. Similarly annual vegetable crops like capsicum, cucurbits, cauliflower and root and tubers and flower crops urgently need crop simulation models. Once these simulation models are available, prediction of impacts and vulnerability of existing areas under these horticultural crops under climate change scenario can be examined, and new target areas for possible shifting of species and varieties for cultivation can be identified. Possible adaptation measures to reduce the impact of climate change can also be studied through simulation models for suggesting changes in management practices. Development of crop simulation models for horticultural crops in India is now a priority area of research.

1.8 Adaptation Strategies

To address the adverse impacts of climate change on productivity and quality of horticultural crops, we need to develop sound adaptation strategies. The emphasis should be on development of production systems for improved water-use efficiency and to adapt to the hot and dry conditions. Strategies like changing sowing or planting dates in order to combat the likely increase in temperature and water stress periods during the crop-growing season. Modifying fertilizer application to enhance nutrient availability and use of soil amendments to improve soil fertility for enhancing nutrient uptake. Providing irrigation during critical stages of the crop growth and conserving soil moisture reserves are the most important interventions. The crop management practices like mulching with crop residues and plastic mulches help in conserving soil moisture. In some instances, excessive soil moisture due to heavy rain becomes a major problem, and it could be overcome by growing crops on raised beds.

In addition to employing modified crop management practices, the challenges posed by climate change could be tackled by developing tolerant varieties. Several institutions have evolved hybrids and varieties, which are tolerant to heat and drought stress conditions. They must be used very effectively to combat the effect of climate change depending upon their performance in a given agro-ecological region. Efforts should be intensified to develop new varieties suitable to different agro-ecological regions under changing climatic conditions. In comparison to annual crops, where the adaptation strategies can be realized relatively fast using a wide range of cultivars and species, changing the planting dates or season, planting and rearrangement of orchards requires a consideration of the more long-term aspects of climate change. Therefore, before resorting to any adaptation option, a detailed investigation on the impact of climate change on perennial crops is necessary.

1.9 Can the Climate Change be Mitigated?

The long-time horizon of perennial crops creates situations like favourable areas may become unfavourable during the life of a single orchard. The choice of a variety is complicated by the risk that the best variety for the current climate may be poorly suited for future climates. Thus, while adaptations such as planting new varieties and shifting to new areas may reduce impacts in the long-term, short-term losses may largely be unavoidable. In wine grape, each grape variety grows in a range of temperatures, and for each variety it is possible to define climates for premium wine production. The physiological and morphological differences between varieties (genotypes) enable production over a relatively large range of climates and depending upon the suitability to different growing areas the cultivars may be adopted. In situations where there is a strong consumer preference for a select cultivar and also the suitable varieties are not available to adapt to the changing climate of a particular growing region, the option of using rootstocks for better performance of the scion cultivars could be explored.

1.9.1 Mitigating Climate Change

Although climate change is a reality, CO_2 and methane are likely to increase which may cause impact in terms of increased temperature, more demand for water and increased biotic and abiotic stresses. Mid-hill chilling will not be enough to induce flowering in apple, and high temperature may cause desiccation of pollen, shrivelling of fruits resulting in reduced yield and more failure of the crops. These are the likely impact which causes the concerns. But there are innumerable examples to cite that climate has been changing and the technologies have helped in mitigating the problem. As a matter of fact, grape is a temperate fruit, which has been largely grown under cool climate, be it for table purposes or for winemaking. But the technological change in plant architecture and production system management has helped to produce grape in tropical situation, with highest productivity in the world. Salinity and alkalinity were a great problem for successful growing of grape, but identification of suitable rootstocks has made it highly productive. If we look to potato, tomato, cauliflower and cabbage, these are thermo-sensitive crops and were productive only under long-day conditions in temperate climate. But development of heat-tolerant cultivars and adjustment in production system management has made it possible with very high productivity, even in subtropical and mild subtropical and warmer climates. These are the past experiences, which clearly bring home the point that through innovative research, threat of climate change could be converted into the opportunity, but will need visualization of likely change, its impact and planning to mitigate its bad impact. Now, available tools of biotechnology could add for speedier delivery of research results.

1.10 Critical Gaps

Based on the studies conducted in various institutes so far for understanding, the impacts of climate change on horticultural crops and adaptation options following critical gaps have been identified and listed here:

- The database on present climatic conditions, future climate scenarios and likely climatic risks associated with different agro-ecological regions growing horticultural crops needs top priority.
- The information on impacts of high temperature, limited and excess moisture stresses, elevated CO_2 concentrations and their interaction at critical stages of crop growth of horticultural crops under Indian conditions is scarce and needs urgent attention.
- The vast historic data available with AICRP centres on different crops across the country on weather, crop performance, phenology, yield and incidence of pest and diseases needs thorough analysis.
- The documentation on the emergence and incidence of pests and diseases under climate variability and climate change conditions in horticultural crops in different growing regions at the national level across the institutes is very much essential in devising new strategies in the management of pest and diseases.
- The integrated resilient adaptation strategies for specific critical stages of crops, seasons and agro-ecological regions under climate change situations need to be developed not only for sustaining but for enhanced production of horticultural crops.
- Quantification of the carbon emission through the production, protection and post-harvest management of horticultural crops and sequestration potential of perennial crops and horticulture production systems needs priority.
- There is need to develop ecofriendly and green technologies for production, protection and post-harvest management of horticultural crops and landscaping practices to mitigate the emission of greenhouse gases.

1.11 Future Strategies

Depending on the vulnerability of individual crop and the agro-ecological region, the crop-based adaptation strategies need to be developed, integrating all available options to sustain the productivity. Developing strategies and tools to comprehensively understand the impact of climate change and evolve possible adaptation measures in horticultural crops is less understood. To enhance our preparedness for climate change and to formulate a sound action plan, we need to identify gaps in vital information and prioritize research issues from point of view of farmers, policy planners, scientists, trade and industry. It is imperative to deliberate upon the likely changes which can happen in next 50–100 years; how these changes could affect growth, development and quality of horticultural crops; what are the technologies which shall help to mitigate the problem; and what kind of innovative research should be done to overcome the challenges of climate change. Thus, policy issues, adaptation strategies and mitigation technologies could be worked out, and challenges could be converted into opportunity with the updating of following:

- Priority of education, research and development and policy implications for enhancing adaptive capacity of Indian horticulture to climate change
- Capacity assessment of Indian horticulture for mitigation of greenhouse gases
- Appropriate short- and long-term action plan to mitigate the impact of climate change in horticulture

1.12 Conclusions

Climate change per se will have impact on horticultural crops due to erratic rainfall, more demand for water and enhanced biotic and abiotic stresses. However, the changes will not be only harmful, as enhanced CO_2 concentration may enhance faster photosynthesis and increased temperature may hasten the process of maturity. However, measures to adapt to these climate change-induced changes are critical for sustainable production. Increased temperature will have more effect on reproductive biology, and reduced water may affect the productivity, but adaptive mechanism like time adjustment and productive use of water shall reduce the negative impact. The strategies must have to identify the gene tolerant to high temperature, flooding and drought, nutrient efficient cultivars and production system for efficient use of nutrient water. Strategies have to address the enhanced water-use efficiency and cultural practices that conserve water and promote crop. Development of climate-resilient horticultural crops which are tolerant to high temperature, moisture stress, salinity and climate proofing through genomics and biotechnology would be essentially required. This would need highly prioritized research to address the impact of climate change.

Enhancing the adaptation of tropical production system to changing climatic condition is a great challenge and would require integrated efforts and an efficient and effective strategy to be able to deliver technologies that can mitigate the effects of climate change on diverse crops and production systems. Knowledge of carbon sequestration, especially through perennial horticulture, needs to be enhanced, which could be utilized for enhancing the income through trading of carbon. Research must address all the strategies which can convert the challenges into the opportunity. Concerted and integrated efforts with effectiveness and efficiency would definitely make us stronger to face the challenges and meet the ever increasing demand for food.

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2

Impacts of Climate Change on Horticulture Across India

S.L.H.V. Prasada Rao, C.S. Gopakumar,
and K.N. Krishnakumar

Abstract

In India, increase in mean annual maximum temperature was 0.76°C and mean minimum temperature was 0.22°C. Increase in annual mean temperature was 0.49°C during the period, commencing from 1901 to 2003. In terms of increase in temperature, the West Coast of India is warmer, followed by the Northeast India and the Western Himalayas when compared to other regions of the country. The years 2009 and 2010 were recorded as the warmest in the country since 1901. Increase in temperature and rainfall was noticed in the country in tune with the global warming and climate change though spatial and seasonal differences were evident. At the same time, rainfall during the monsoon season was deficit in recent years like 1987, 2002 and 2009 which adversely affected the food grains production in India. In the case of thermo-sensitive crops like tea, coffee, cardamom, cocoa, cashew and black pepper, the projected increase of 2–3°C in temperature may directly affect the cropped area and productivity. The observations on mango and cashew flowering also indicated that increase in night temperature during winter is a concern as seen in 2010. The coconut productivity in Kerala is likely to decline under the projected climate change scenario as the occurrence of floods and summer droughts is likely to affect the crop adversely, and their frequency is likely to increase under the projected climate change scenario. Therefore, proactive technologies need to be developed against the global warming and climate change for sustenance of crop production in horticulture as a part of "climate resilient horticulture".

2.1 Introduction

Increase in temperature is likely to impact the atmospheric processes, and the occurrence of weather abnormalities like floods, droughts and cold and heat waves is likely to increase in ensuing

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decades under the projected climate change scenarios. The super cyclone in 1999 across the Orissa Coast adversely affected the cashew plantations to a considerable extent through uprooting of trees in sandy soils. All the fruit crops suffered heavily due to unprecedented cold wave in 2002–2003 across the North Indian states. At the same time, temperate fruit crops such as apple, plum and cherry gave high yield due to extended chilling. In contrast, the heat wave in March 2004 in the same belt adversely affected apple, tea, potato and vegetables. Potato and vegetables matured early, and heavy crop losses were noticed due to abnormal increase in temperature as a result of heat wave (Prasad and Rana 2006). The prolonged droughts during summer adversely affected the crops like cocoa, black pepper, coconut, coffee, tea and cardamom along the West Coast in 1982–1983 and 2003–2004 (Rao et al. 2008). Increase in night temperature in several parts of the country during winter 2010 adversely affected mango flowering. Therefore, there is a need for proactive measures for sustenance of horticulture against the occurrence of cold and heat waves, floods and droughts as well as against sea level rise as a part of "National Climate Resilient Horticulture" under projected climate change scenario as their frequency is likely to increase in the ensuing years. Keeping the above in view, an attempt has been made to understand the impact of climate change on horticultural crops across different regions of the country.

Temperature data (maximum and minimum) for the period from 1901 to 2003 for different zones of the country and for the country as a whole were downloaded from the IITM website *www.tropmet.res.in*. Trends were worked out for maximum, minimum and mean temperatures and temperature range for all the zones. Summer (March to May) maximum temperature and winter (December to February) minimum temperatures were also collected for all the zones, and trends were worked out. The data on warm years during the recent decade/century were also downloaded. Rainfall trends for various periods for different zones were also worked out using the data downloaded from the *www.tropmet.res.in*. Crop data on area, production and productivity of horticultural crops were collected from the published sources. Attempts were made to understand the impact of climate change on the selected horticultural crops across the country through agroclimatic analysis.

2.2 Climate Change Scenarios Across India

The increase in annual mean temperature over different zones of the country varied between 0.2°C and 0.73°C with an overall increase of 0.49°C for the country as a whole. The West Coast of India is warmer (0.73°C), followed by the Western Himalayas (0.7°C), the Northeast India (0.63°C) and the East Coast of India (0.52°C) in terms of the mean annual temperature. A least increase (0.2°C) in annual mean temperature was noticed across the Northwest India over a period of 103 years, commencing from 1901 to 2003 (Table 2.1).

The increase in annual maximum temperature in different zones of the country varied between 0.53°C and 1.24°C with an overall increase of 0.76°C for the country as a whole. The West Coast of India is warmer (1.24°C), followed by the North East India (1.04°C), the Western Himalayas of India (0.93°C), the North Central India (0.74°C) and the East Coast of India (0.67°C). In the case of summer maximum temperature, it varied between 0.39°C and 1.02°C with an overall increase of 0.65°C for the country as a whole. The West Coast of India, the Western Himalayas and the Northeast of India recorded a high of 1.02°C, 0.99°C and 0.82°C, respectively (Table 2.2).

In the case of annual minimum temperature, the Western Himalayas of India showed highest increase (0.48°C), followed by the Interior Peninsular India (0.45°C) and the East Coast of India (0.36°C). Interestingly, the Northwest India showed cooling tendency (–0.14°C) rather than warming in terms of minimum temperature. In the case of winter minimum temperature, the Western Himalayas of India showed warming tendency (0.84°C), followed by the Interior Peninsular India (0.70°C) and the East

Table 2.1 Increase in annual temperature across various zones of India

Sl. no.	Zone	Increase in temperature (°C) Max (°C)	MinT (°C)	MeanT (°C)
1	All India	0.76°C	0.22°C	0.49°C
2	West Coast of India	1.24°C	0.22°C	0.73°C
3	East Coast of India	0.67°C	0.36°C	0.52°C
4	Northeast India	1.04°C	0.19°C	0.63°C
5	Northwest India	0.55°C	–0.14°C	0.20°C
6	North Central India	0.74°C	0.26°C	0.49°C
7	Interior Peninsular India	0.53°C	0.45°C	0.49°C
8	Western Himalayas of India	0.93°C	0.48°C	0.70°C

Table 2.2 Increase in summer maximum temperature across various zones of India

Sl. no.	Zone	Increase in summer maximum temperature (°C)
1	All India	0.65°C
2	West Coast of India	1.02°C
3	East Coast of India	0.50°C
4	Northeast India	0.82°C
5	Northwest India	0.50°C
6	North Central India	0.69°C
7	Interior Peninsular India	0.39°C
8	Western Himalayas of India	0.99°C

Table 2.3 Increase in winter minimum temperature across various zones of India

Sl. no.	Zone	Increase in winter minimum temperature (°C)
1	All India	0.42°C
2	West Coast of India	0.12°C
3	East Coast of India	0.65°C
4	Northeast India	0.64°C
5	Northwest India	–0.35°C
6	North Central India	0.56°C
7	Interior Peninsular India	0.70°C
8	Western Himalayas of India	0.84°C

Coast of India (0.65°C) and the North East India (0.64°C). The night temperature was low (–0.35°C) across the Northwest India, indicating cold nights during winter while warm nights relatively across the remaining parts of the country (Table 2.3). Such trend of cool and warm nights may not be always true across the country under the projected climate change scenario. Interestingly, the minimum temperature was declining during the southwest monsoon if the country is taken as a whole.

The rate of increase in maximum temperature was high (1.0°C) in post monsoon season, followed by winter (0.9°C) when compared to that of other seasons (Fig. 2.1). It is true in the case of minimum temperature also. On an average, the increase in temperature range was 0.54°C. It is a concern in northern states during the *rabi* season as winter crops are adversely affected due to temperature increase. It is more so in the case of temperate fruit crops. Increase in temperature might be one of the reasons for glaciers melt across the

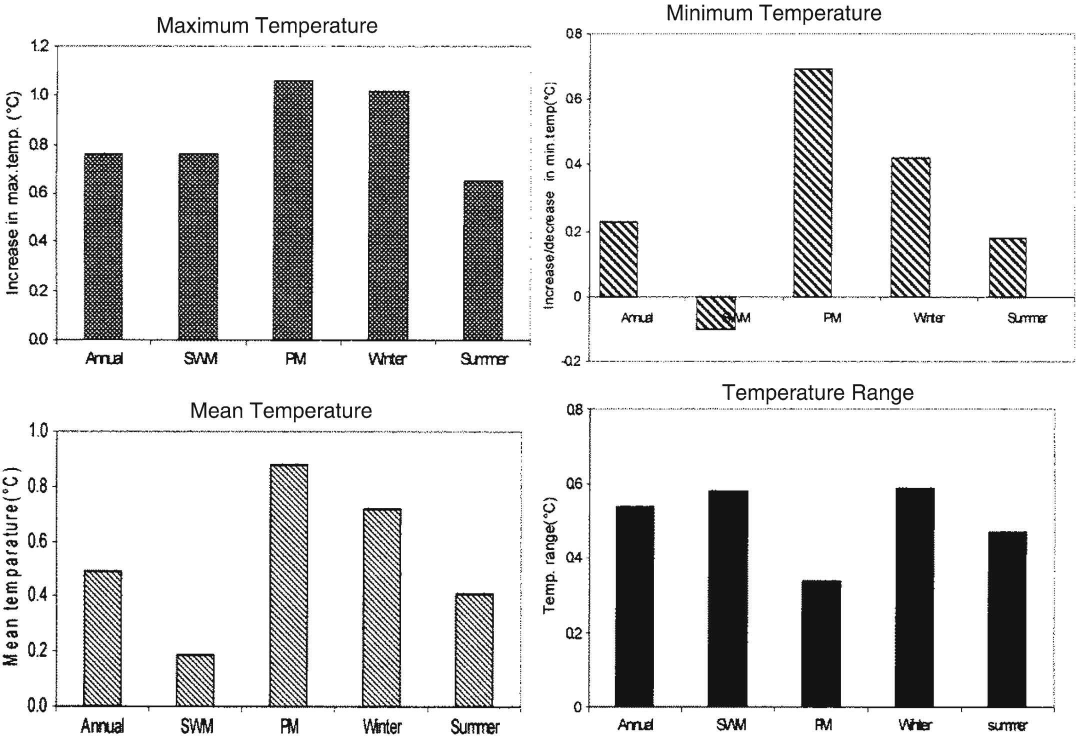

Fig. 2.1 Annual and seasonal temperature rate of increase in maximum, minimum, mean and range (°C) over India

Himalayas. It is again a concern and threat to the two rich hotspots of biodiversity in the country as the rate of increase in temperature is relatively high across the Western Ghats and Western Himalayas of India.

There was a marginal increase in annual rainfall as well as seasonal rainfall during the southwest monsoon and post monsoon season since last 194 years (1813–2006) for the country as a whole. Similar trend was noticed in all the zones in annual and southwest monsoon rainfall except in Northeast India, where the decline in rain fall was insignificant. Such trend was seen during post monsoon season in the Eastern Peninsular India and the North Central India. Rainfall is likely to increase between 5% and 25% all over the tropics in the next 25–30 years on account of climate change according to climate change projection models.

The study reveals that the West Coast of India is warmer followed by the Northeast India and the Western Himalayas. The warming over the Northwest India is mild, and cooling was noticed rather than warming during winter. Although there had been a distinct rise in temperatures since 1970, the rate of increase in the last 15 years was higher in the country compared to the preceding 15 years. While the rise in temperature was 0.2°C during 1901 to 2000, it was 0.4°C between 2001 and 2010, according to the Indian Meteorological Department. Out of 13 warmest years, 8 years fell during the decade 2001–2010. 2001, 2002, 2003, 2004, 2006, 2007, 2009 and 2010 were the warmest years in the recent decade. The increase in mean temperature during the recent decade (2001–2010) was 0.6°C. The years 2009 and 2010 were recorded as the warmest in the country since 1901. Increase in temperature and rainfall was noticed in the country in tune with the global warming and climate change though spatial and seasonal differences were evident but insignificant in the case of rainfall since last two centuries. At the same time, rainfall during the monsoon season was deficit in recent years like 1987, 2002 and 2009 during which the Indian food grains production was adversely affected. The projected maximum and minimum temperature from the base period of 1961–1990

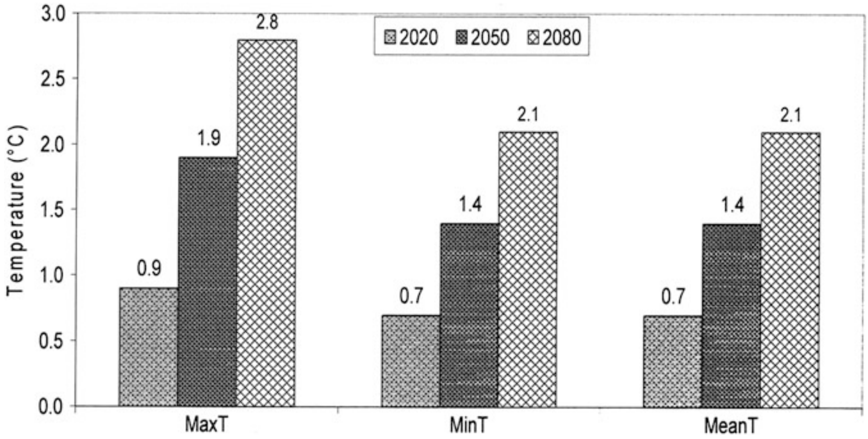

Fig. 2.2 Projections in rate of increase in temperatures across India by 2020, 2050 and 2080

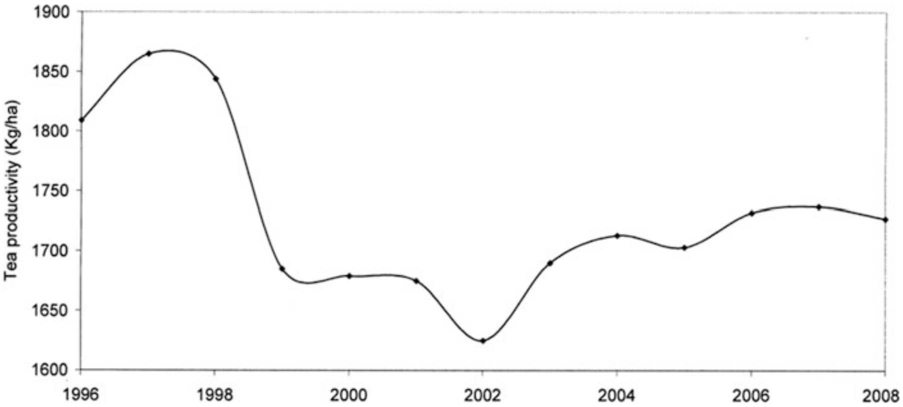

Fig. 2.3 Tea productivity in India from 1996 to 2007

assuming a linear trend would be 2.8°C and 2.1°C, respectively, by 2080 A.D (Fig. 2.2). Of course, the rate of increase in ensuing decades may vary depending upon the emission of greenhouse gases, in particular the emission of CO_2 as it accounts up to 70–75% of increase in atmospheric temperature.

2.3 Effect of Climate Change on Tea Productivity

There was a phenomenal increase in the case of tea productivity from 1918 to 2008 with stagnation in 1930s (500–600 Kg/ha in majority of the years) and early 1940s (less than 800 Kg/ha) and reached its peak productivity during 1996, 1997 and 1998 (greater than 1800 Kg/ha). Of course, the annual variations within the phenomenal increase in productivity could be attributed to weather changes under better management and cultural practices. However, the decline in tea productivity since 1999 is a concern (Fig. 2.3). The reasons for decline of tea productivity in recent years could be many, including price fluctuations, senile and neglected plantations and shortage of plantation workers due to low daily wages in addition to warming across the tea-growing regions as the recent decade was the warmest since records are maintained. The studies along the West Coast indicated that the optimum temperature for tea productivity appears to be 26.5°C in terms of maximum temperature while 17.5°C in the case of minimum temperature. Increase in temperature during the last decade appears to be adversely affecting the tea productivity (Gopakumar 2011). Therefore, warming across the tea-growing area is a threat to tea productivity. Similar was the case in coffee productivity also in the absence of blossom and backing showers. Crop growth simulation models outside the country indicated that a rise of 2°C in temperature is likely to affect the area under tea and coffee adversely. However, detail studies need to be carried out on regional scales to establish the impact of global warming and climate change on tea as well as coffee productivity for which various agencies involved in the industry should take initiatives as a part of climate resilient horticulture.

2.4 Climate Change and Coconut Productivity

In the case of coconut, it is projected that the coconut productivity on all India basis is likely to go up by up to 4% by 2020, up to 10% by 2050 and up to 20% by 2080 over current yields due to global warming and climate change. Along the West Coast, yields are projected to increase by up to 10% by 2020, up to 16% by 2050 and up to 39% by 2080, while in the East coast yields are projected to decline up to 2% by 2020, 8% by 2050 and 31% by 2080 over current yields (Kumar and Aggarwal 2009). Yields are projected to go up in Kerala, Maharashtra and parts of Tamil Nadu and Karnataka, while they are projected to decline in Andhra Pradesh, Orissa, Gujarat and parts of Tamil Nadu and Karnataka. It reveals that coconut productivity across the state of Kerala is likely to increase due to global warming and climate change. However, the model results cannot be taken into account on real-time basis as the global warming is likely to increase the frequency of occurrence of floods and droughts, which affect coconut production adversely as seen in the past in the state of Kerala. Moreover, any increase in temperature during the second phase of nut development is likely to influence the nut size and thereby the copra outturn and oil content. The second phase of nut development is more sensitive to high temperature. In addition, the inputs like projected CO_2 levels used in the model may also not be realistic. In contrast to the Infocrop model output of Kerala, a marginal decline in coconut productivity was noticed under field conditions from one tri-decade to another tri-decade. The coconut productivity in Kerala on tri-decadal basis was high (5762 nuts/ha) during 1951–1980 when compared to that of 1981–2009 (5670 nuts/ha). The percentage decline was 1.6% in 1981–2009 when compared to that of 1951–1980. There was a distinct difference in rainfall distribution, aridity index, number of summer droughts, moisture index and temperature from 1951–1980 to 1981–2009 (Fig. 2.4). Increase in temperature, aridity index, number of severe summer droughts and decline in rainfall and moisture index were the major factors for a marginal decline or stagnation in coconut productivity over a period of time. It is a clear signal of decline in coconut productivity due to global warming and climate change. In view of the above, there is an urgent need for proactive measures as a part of climate change adaptation to sustain coconut productivity in the state of Kerala, which is having a lion share in coconut productivity of the country. Therefore, the coconut productivity is likely to decline under the projected climate change scenario as the occurrence of floods and droughts is likely to affect the crop adversely, and their frequency is also likely to increase under the projected climate change scenario. Similar case studies were also taken up by the authors in several plantation and spice crops, viz. cashew, cocoa, cardamom, tea, coffee, rubber and black pepper across the West Coast of India, where the rate of warming is relatively high.

2.5 Conclusion

The impact of climate change on horticulture crop like coconut could be seen indirectly in the form of climate variability rather than directly due to increase in temperature. In the case of thermo-sensitive crops like tea, coffee, cardamom, cocoa, cashew and black pepper the projected increase of 2–3°C in temperature may directly affect the cropped area and productivity.

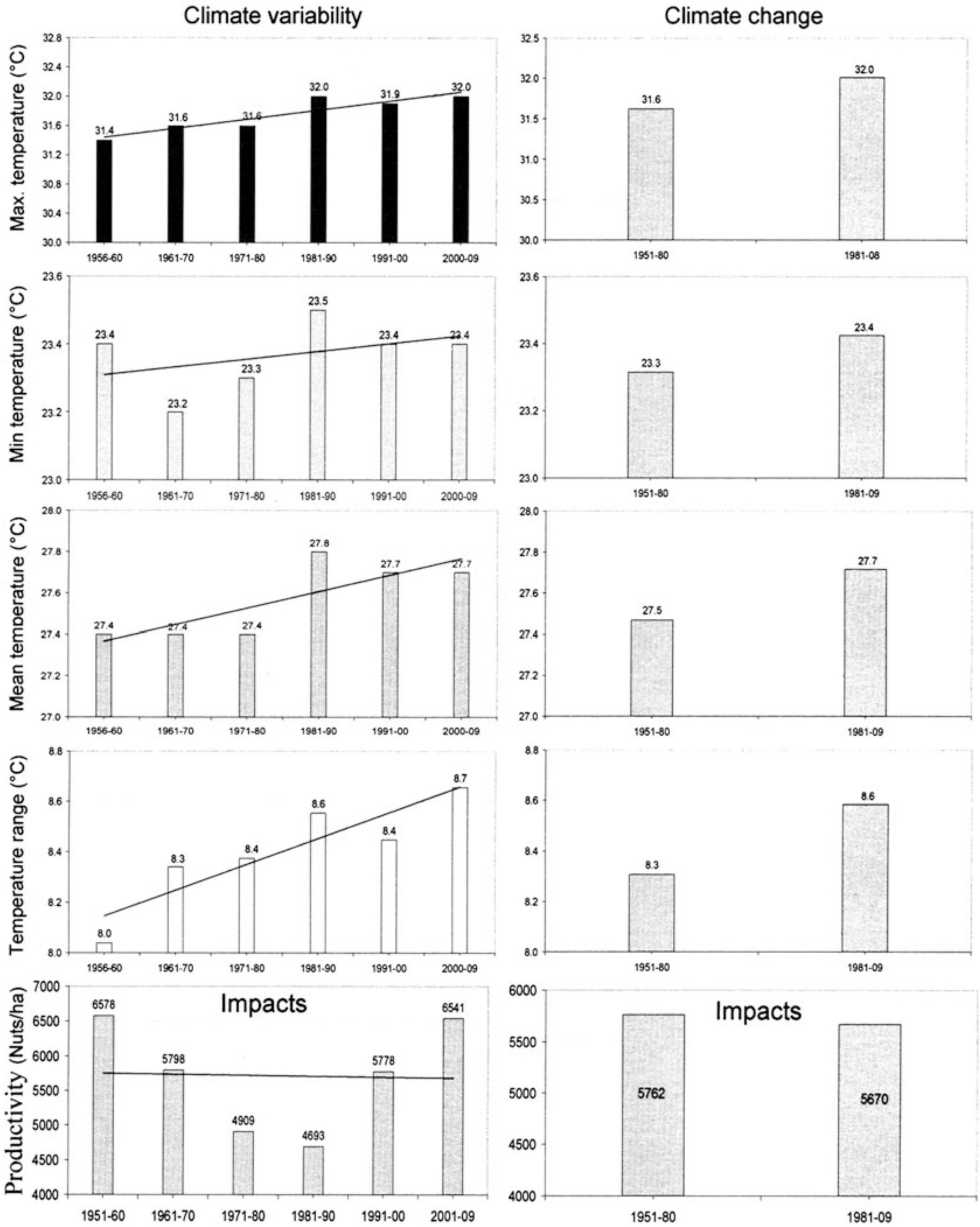

Fig. 2.4 Decadal and tri-decadal maximum, minimum, mean temperature, temperature range and productivity of coconut

The observations on mango and cashew flowering also indicated that the increase in night temperature during winter is a concern in recent years as seen in 2010. Therefore, proactive technologies need to be developed against the global warming and climate change for sustenance of crop production in horticulture as a part of "climate resilient horticulture".

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3

Modelling Climate Change Impacts, Adaptation Strategies and Mitigation Potential in Horticultural Crops

Soora Naresh Kumar

Abstract

Increasing weather extremes and climatic risks due to global climate change have been posing immense challenge to agricultural and horticultural crops. However, horticulture offers vital adaptation strategy for nutritional security and sustainable farm income. Therefore, it is imperative to understand the impacts of climate change on various horticultural crops and to identify the adaptation strategies to minimize the adverse effects of climate change and to maximize the positive influence of it, if any. Further, perennial fruit and plantation crops offer immense scope for climate change mitigation through carbon sequestration and modification of microclimate. In spite of recent efforts, a lot of knowledge gap exists with respect to impact assessments at regional level, corresponding adaptation strategies and mitigation potential. Lack of or non-accessibility of suitable simulation models is one such major constraint for looking forward at regional and national level. Model development (wherever necessary), improvement and integration (climate-crop-hydrological-socioeconomic models) are needed for bridging the gap between research and policy for holistic resilience at regional scale. This will help to analyse the climate resilient plants, farms and regions. Apart from these, the ecosystem services from horticulture can also be quantified using the models. Therefore, need is to strengthen and initiate focused research programmes to address the identified gaps.

3.1 Climate Change: Global and Indian Scenarios

Overexploitation of fossil fuels ever since the beginning of industrial era led to increased concentration of green house gases (GHGs), viz. carbon dioxide, methane, nitrous oxide and sulphur

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dioxide, in the atmosphere. Increase in the concentration of these GHGs is responsible for global climate change. Climate change may be due to natural internal processes or external forcing and due to persistent anthropogenic changes in the composition of the atmosphere or in land use. However, United Nations Framework Convention on Climate Change (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 UNFCCC thus makes a distinction between ‘climate change’ attributable to human activities altering the atmospheric composition and ‘climate variability’ attributable to natural causes.

The atmospheric concentration of CO_2 has never been so high as it is now. The CO_2 concentration has increased from a pre-industrial value of about 280–393 ppm in 2012. Similarly, the global atmospheric concentration of methane and nitrous oxides and other important GHGs has also increased considerably. This has resulted in warming of the climate system by 0.74°C between 1906 and 2005 (IPCC 2007a). Increased frequency of drought years in past 30 years has been noticed not only at global but also in Indian context. Sea level rise, increased frequency of frosts, heat and cold waves have added to woes of mankind particularly that of farmers. The global climate models project rise in temperature, increased variability in rainfall and increase in extreme weather events challenging the sustainability of agricultural production and farm income. Even though, for Indian region (south Asia), the IPCC has projected 0.5–1.2°C rise in temperature by 2020, 0.88–3.16°C by 2050 and 1.56–5.44°C by 2080 apart from increase in rainfall variability and weather extreme events, depending on the future scenario development (IPCC 2007b), a lot of spatio-temporal variations are likely to occur. For instance, analysis of PRECIS (a regional climate model) outputs on climate projections for India indicated that, in general, increase in temperature is likely to be more during winter (October–March; rabi) season than in monsoon (June–September; kharif) season (Fig. 3.1). For a medium scenario (A1b-2030), seasonal minimum temperature is likely to increase more in Uttar Pradesh (UP), Bihar, Rajasthan, Maharashtra and peninsular India, while the seasonal maximum temperature is likely to increase more in UP, Bihar and peninsular India. Kharif season rainfall is projected to increase more in eastern and central parts of the country. During rabi season, increase in seasonal mean minimum temperature is likely to be more in central and western parts of India, while the mean seasonal maximum temperature is likely to be more in central India. Rabi rainfall is projected to increase in north India, parts of Andhra Pradesh and Maharashtra.

3.2 Climate Change and Indian Horticulture

Climate change causes the increased weather variability and mean change in climatic variables such as temperatures and rainfall. There have been instances of loss of horticultural crops due to climate-related extreme events at regional scale such as high temperatures during March 2004 in north India which caused significant losses to horticultural crops such as tomatoes, onion, garlic and other vegetable and fruit crops (Samra and Singh 2004). Cold wave during December 2002–January 2003 caused considerable damage to horticultural crops such as mango, guava, papaya, brinjal, tomato and potato (Samra and Singh 2003). Similarly cold waves in 2006 affected tomato, potato, mango, guava, banana, papaya, tamarind, wood apple, brinjal, etc. In 2007, late snowfall in Srinagar coinciding with full bloom damaged almonds. High rainfall events in 1998, 2005 and 2010 affected kharif and late kharif crop of onion, while untimely heavy rain in March 2008 in west coast of India reduced the cashew yield and nut quality. However, numerous extreme weather events which are localized, but not recorded, have caused immense loss to the farm and rural household income, contributed to fluctuating market price.

While above-mentioned examples represent the weather extremes due to increased climatic variability, reported shift in apple cultivation to

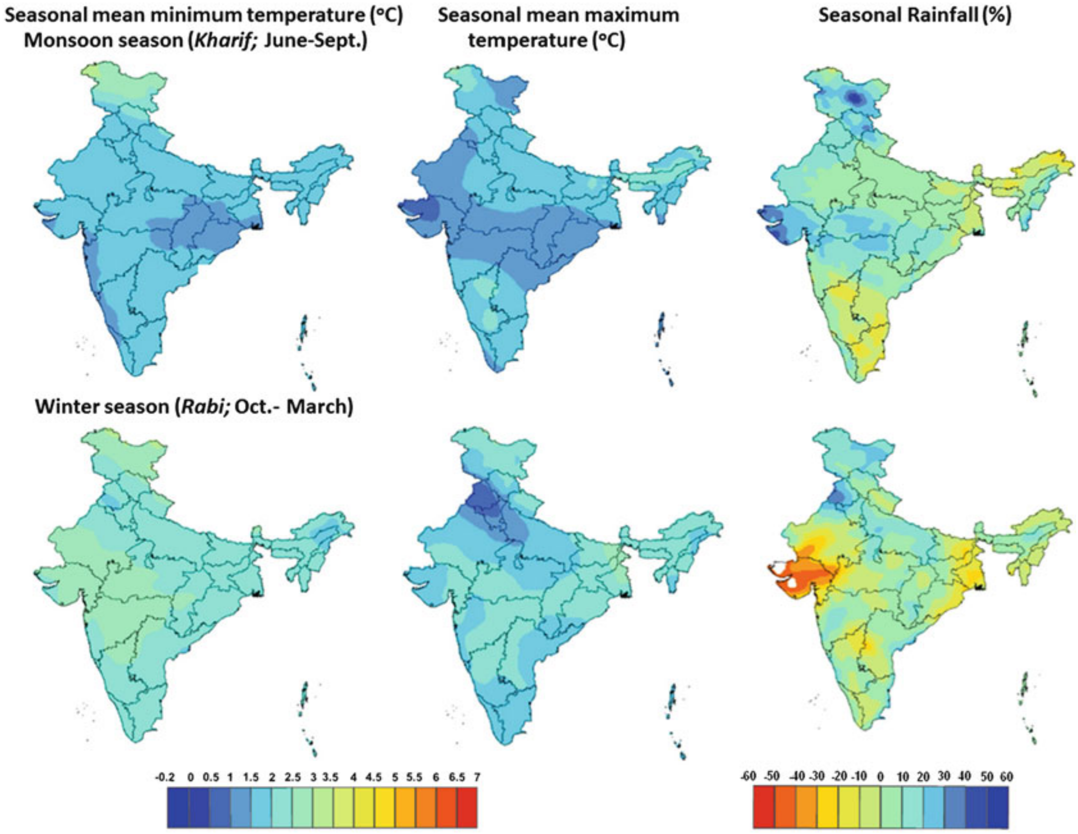

Fig. 3.1 Spatial variation in projected changes in seasonal temperatures and rainfall across India as per the PRECIS, A1b 2030 scenario

higher elevations partly due to non-fulfilment of chilling requirement in Himachal Pradesh is an example of impact of climate change and shift in climatic suitability of areas for a given crop. Since growing horticultural crops is seen as an income enhancement activity by a household, it becomes important to provide scientifically tested suitable low-cost and low-carbon adaptation strategies so as to not only improve the livelihood of the farmers but also to make them resilient to climatic risks. This approach will not only help in nutrient, food and livelihood security but also help to improve the overall adaptation of farm, a major foundation for resilient agriculture at national level.

Climate change impact assessments provided by global studies indicated a probability of 10–40% loss in crop production in India with increases in temperature by 2080–2100 (Rosenzweig and Parry 1994; Fischer et al. 2002; Parry et al. 2004; IPCC 2007b). Even though Indian studies on this theme generally confirm similar trend of agricultural decline with climate change (Aggarwal and Sinha 1993; Rao and Sinha 1994; Lal et al. 2008; Saseendran et al. 2000; Mall and Aggarwal 2002; Aggarwal and Mall 2002; Aggarwal 2003; Aggarwal 2008), significant spatial variations in impacts are reported for sorghum (Srivastava et al. 2010), maize (Byjesh et al. 2010) and compendium of crops (Naresh Kumar et al. 2011).

Economically Indian horticulture contributes about 30% to national agricultural GDP and substantial earner of foreign exchange. The growth rate of horticultural sector, which is at record high in recent years, needs to be further enhanced in order to meet the targeted agricultural growth rate of 4. In

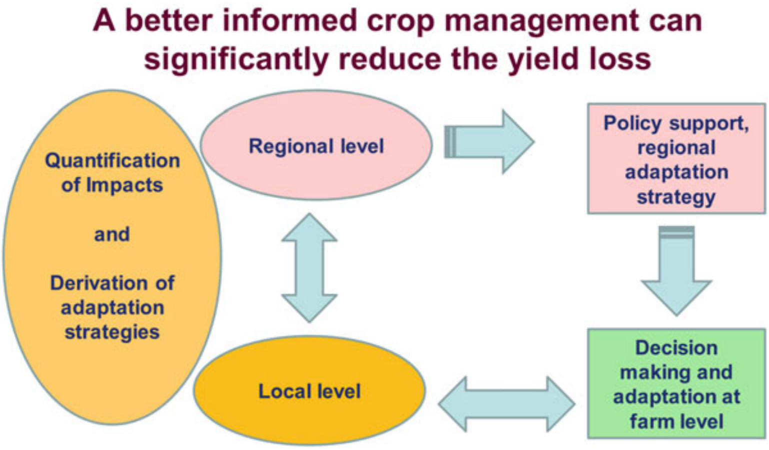

Fig. 3.2 The framework for impact and adaptation assessments at local and regional level

the era of global economy and increased purchasing power, the demand for horticultural crops for domestic and international markets has been ever increasing, particularly for quality produce. Climate change complicates this challenge as it inflicts increased variability in quality and production. The understanding and assessing of the regional impacts of climate change on crops, therefore, become an indispensable activity as also that of developing the adaptation strategies at regional and farm level for eventual implementation (Fig. 3.2). These can be done at several levels, viz. household, community, village, cluster of villages, block, district, state and national level. The regional level assessments provide important inputs for policy support, very crucial for development of horticultural sector in the country. The compilation of available information on response of horticultural crops to elevated CO_2 and temperature from Indian studies and also some of the observed impacts of climate-related events on horticultural crops in India has been documented earlier (Aggarwal 2009; Naresh Kumar and Aggarwal 2009; Chadha and Naresh Kumar 2010; Naresh Kumar 2011; Naresh Kumar et al. 2008b, 2010, 2012). Although a number of studies have projected impacts of climate change on field crops, horticulture sector, the major component of agriculture in India, did not receive deserved attention as far as climate change impact assessments are concerned, in spite of it being highly diverse and offers scope for resilience to climatic risks. Apart from this, perennial horticulture has immense potential to play an important role in GHG mitigation through carbon sequestration.

3.3 Approaches for Quantification of Crop Response to Elevated CO_2, Change in Temperature and Rainfall in Horticultural Crops

The response of crops to elevated CO_2, change in temperature and rainfall is being quantified using either field experiments or meta-analysis and simulation modelling. In field experiments, quantifications are done by growing crops in controlled environment facilities or Open Top Chamber (OTC), Free Atmospheric Carbon dioxide Enrichment (FACE), Free Atmospheric Temperature Elevation (FATE) and T-FACE facilities where both temperature and CO_2 are modified. Rain-out shelters and rainfall simulators are used for quantifying the rainfall and crop growth and yield relationship. These studies provide vital information on crop response to individual or a combination of factors, in spite of being costly and time-taking procedure. However, the information generated cannot be generalized for different management or climatic conditions and cannot be extrapolated to regional/ state or national level. Meta-analysis, the second

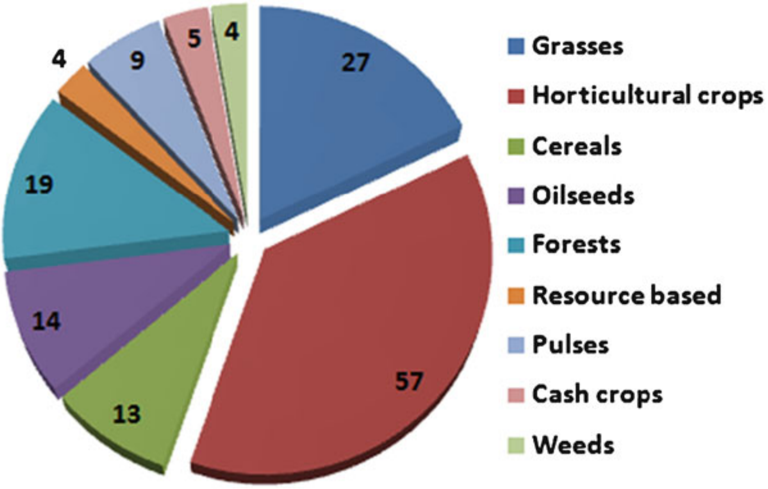

Fig. 3.3 Breakup of the availability of crop models based on the type of crops. Numerical values in each category indicate the number of crops for which models are available

approach, includes analysis of past data from experiments and surveys for quantifying the responses. However, this approach is constrained by the availability of suitable data and details.

Simulation models are strong tools which provide opportunity to use various climate change scenarios in combination with different management parameters for analysing the regional impacts, adaptation and vulnerability. Apart from these, well-developed crop simulation models provide opportunity to assess the impacts of climatic variability on crop growth. Such studies provide the guidelines for (1) relative advantage of adaptation strategies to be followed for minimizing the climate change impacts, (2) best possible adaptation strategy, (3) technology development needs, (4) research gaps, (5) regional spatial and temporal variation and (6) regional policy direction. Further, crop simulation models coupled with GIS prove to be strong tools for not only impact, adaptation and vulnerability assessments but also for land use change and land use plan. In this chapter, an effort is made to provide a framework of modelling approach for horticultural crops with examples drawn for this sector.

In order to assess the impacts of climate change at regional scale using simulation approach, one needs to have a model which is well calibrated and validated for diverse management and environmental conditions. Even though globally models are developed for 152 crops (Fig. 3.3), their suitability, availability and accessibility become major limitations. A survey of literature indicates that models are available for about 57 horticultural crops, but many of these do not have the capabilities to simulate the climate change impacts either. Even indigenously developed InfoCrop (at IARI) also has just two horticultural crops, viz. potato (Singh et al. 2010) and coconut (Naresh Kumar et al. 2008a) so far. DSSAT is having models for some horticultural crops, which can be used after calibration and validation. Therefore, selection of model(s) is one of the important steps in assessments studies. Since only a few horticultural crops are having suitable simulation models for climate change studies, there is a need for developing the simulation models for many horticultural crops, particularly for perennial plantation crops.

3.4 Modelling and Climate Change Studies

In climate change research, a cascade of simulation models is in operation while deriving the impacts and adaptation. The output from the higher-level model is input into the next lower-level model (Fig. 3.4). However, the sequence given in Fig. 3.4

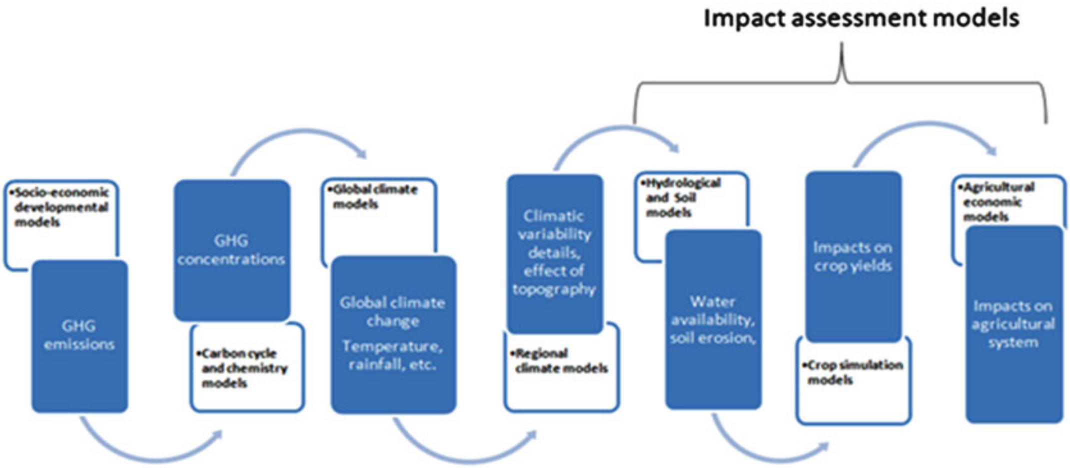

Fig. 3.4 The cascading role of simulation models in climate change research (Adopted from Naresh Kumar 2011)

need not be compulsory. The global GHG emission levels in different socioeconomic developmental scenarios are derived by the atmospheric carbon cycle and chemistry models. The concentration of GHGs including that of CO_2 and their radiative forcing is used for running the global climate models (GCM) for deriving the past and future climates. These outputs are further downscaled using regional climate models (RCMs). These climate scenarios are input in to the impact analysis models. The impact analysis models such as crop simulation models and hydrological models can be used independently or interdependently for impact assessments. In fact all models from socioeconomic developmental models onwards can be termed impact models, since the socioeconomic developmental policies and their implementation influence the GHG emissions with cascading effect on climates and dependent sectors down the line. It needs to be realized that all these models, which are simplified representation of complex natural, biophysical and socioeconomic interactions, have limitations, assumptions and work in certain boundary conditions.

Each step in the modelling exercise (Fig. 3.4) also has some inherent uncertainties associated with it. In spite of unavoidable uncertainties in modelling, particularly with respect to climate models, the impact assessments at regional and national level provide direction on possible impacts and also provide insights for better preparedness to reduce the adverse impacts of climate change.

Therefore, use of more than one strategy and coupling of strategies provides more robust assessments and information. Integrated assessments using (1) controlled environment facilities such as OTCs, (2) field experiments/multilocation trails, (3) lab experiments, (4) surveys, (5) simulation model, (6) past data analysis and (7) meta-analysis will be highly useful for robust analysis (Naresh Kumar 2011). Apart from these, integration of simulation models provides integrated assessments on impacts and adaptation strategies.

3.5 Steps in Crop Simulation Analysis

Before simulation analysis, as a first step, one needs to be clear about the information or assessment sought, availability and suitability of data, models, modelling skills, etc. Once suitable model is selected, the steps that follow are:

3.5.1 Development of Database of Experimental Records

5.1.1. Varietal characteristics such as days to 50% germination, flowering, maturity, base and optimal temperatures for above phenophases, time series data on LAI, dry matter and crop nitrogen uptake and grain yield, grain nitrogen, number of grains m^2 and radiation use efficiency

5.1.2. Crop management information such as time and depth of sowing, time and dose of application of fertilizers, organic matter, irrigation and pest incidence

5.1.3. Soil characteristics such as texture, water-holding characteristics, bulk density and soil pH and nutrient (N, P and K) availability in different depths of soil layers

5.1.4. Daily weather data (minimum and maximum temperatures, rainfall, wind velocity, vapour pressure and solar radiation).

3.5.2 Calibration and Confirmation ('Validation') of Simulation Models

Although the simulation models are flexible enough to perform under a variety of environments and farming conditions, calibration of model is necessary before running the model for a given area. For this, results from the detailed experiments on varietal performance, fertilizer trials and multilocation trails can be made use of. Calibration of a model to simulate the performance of crop in an experiment needs time series data on crop performance such as phenology, LAI, dry matter accumulation and yield. The calibrated model can be used to simulate the crop growth performance in other set of experiments consisting of various treatments for validating the model performance under a range of conditions.

Even though the numerical models of natural systems cannot be verified and validated, they can be confirmed (Oreskes et al. 1994). Conformations of calibrated model against the data from other experiments/locations/conditions are essential where minimum information on crop performance in terms of phenology (days to 50% flowering and physiological maturity), grain yield and dry matter at harvest are available. This confirmed ('validated') model can be used for simulating impacts in that region. Model performance in simulating the observed performance of crop in variable conditions should be assessed through various statistical parameters, viz. model bias error (MBE), root mean square error (RMSE), index of agreement (IA) and model efficiency (ME). This validated model is now ready for application for various studies. Coupling of crop models with GIS and remote-sensing products proves to be a powerful tool for decision support system in agricultural and natural resource management.

3.6 Application of Crop Models for Climate Change Impact Assessments

For simulating the climate change impacts, the following steps are generally followed:

3.6.1 Baseline Weather Data

For climate change impact assessments, one needs to take the baseline data (set of at least past 30 years of defined period). This data can be of observed one or that from GCM or RCM outputs.

3.6.2 Climate Scenarios

Data on climate scenarios (either from GCMs or from RCMs) need to be converted to suitable input format specific to a model. Before that, the approaches followed for using the climate data should be clear. The projected carbon dioxide levels for each scenario also need to be included in the model for simulations. Care needs to be taken to simulate the individual years and take mean of 30 years as the mean scenario year. It is advised not to designate the individual year (2021, 2022, 2023, etc.) to future scenario data as they are scenario projections and not forecasts.

3.6.3 Simulating Baseline Yields

The mean of 30 years yield simulated using the baseline weather data should be taken as the baseline yield.

3.6.4 Simulating Yields in Future Scenarios

The mean of 30 years yield simulated using the climate scenario data should be taken as the yield in future scenarios. The net change in yield in climate change scenario can be expressed as the percentage changes from baseline mean yield. These are called the impacts which can be calibrated to a specific base yield and per cent deviations from such yields in a given scenario.

3.6.5 Simulating Yield Gains Due to Adaptation Options:

The adaptation analysis can be done by quantifying the response of different varieties, sowing time, nutrient management, water management, introduction of new crops, shift in cropping sequences, altered resource management and introduction of new technologies in various climate change scenarios so as to derive the best suitable technology package for reducing impacts of climate change at regional level then upscaling to state and national level. The difference between mean yields in future scenario under business as usual agriculture (impact) and mean yields due to adaptation options in future scenario is called the adaptation gain and may be expressed as per cent gain over impacts. These are called adaptation gains in changed climates.

3.7 Projections of Climate Change Impacts on Horticultural Crops

In India, so far the climate change impact assessments are done for only a few horticultural crops. Simulations using InfoCrop potato model indicated that global climate change may raise production of potato in Punjab, Haryana and Western and Central Uttar pradesh by 3.46–7.11% in A1b 2030 scenario, but in the rest of India particularly in West Bengal and plateau region, potato production may decline by 4–16% (Annual Progress Report 2010). Development of InfoCrop-coconut simulation model for the first time (Naresh Kumar et al. 2008a) has made it possible to study the impact of climatic change on coconut productivity in India. The model was validated for different agroclimatic zones of coconut-growing states. Impact of climate change on coconut yields was assessed using this model. For this fixed change in temperature and CO_2, GCM and RCM climate data were used. Simulation analysis indicated that under all scenarios, coconut productivity on all India basis is likely go up by up to 4% during 2020, up to 10% in 2050 and up to 20% in 2080 over current yields due to climate change. In west coast, yields are projected to increase by up to 10% in 2020, up to 16% in 2050 and up to 39% by 2080, while in east coast yields are projected to decline by up to 2% in 2020, 8% in 2050 and 31% in 2080 scenario over current yields. Yields are projected to go up in Kerala, Maharashtra and parts of Tamil Nadu and parts of Karnataka, while they are projected to decline in Andhra Pradesh, Orissa, Gujarat and parts of Tamil Nadu and parts of Karnataka. However, situations may vary if future irrigation sources are limited particularly in currently irrigated areas such as in Tamil Nadu and Karnataka (Naresh Kumar et al. 2007; Naresh Kumar and Aggarwal 2009; Naresh Kumar et al. 2011).

Using the DOMAIN niche model, possibility of shift in mango-growing regions in future climate is also reported (Rajan 2008). We used EcoCrop model for delineating change in climatic suitability of regions for cultivation of cocoa and areca nut in PRECIS A1b 2030 scenario. Analysis indicated that many regions in future climates may become unsuitable for areca nut cultivation (Fig. 3.5). However, this approach needs further validation and also has several limitations such as it uses only monthly mean data, does not account for weather extremes, CO_2 fertilization effects and adaptation benefits. Even though these models are not developed for use in such studies, they provide important insights into ecological niche in current and future climates.

3.8 Assessing the Potential Adaptation Strategies in Horticultural Sector

Adaptation strategies should include (1) adaptation to progressive climate change, which is long term, and (2) adaptation to short-term climatic

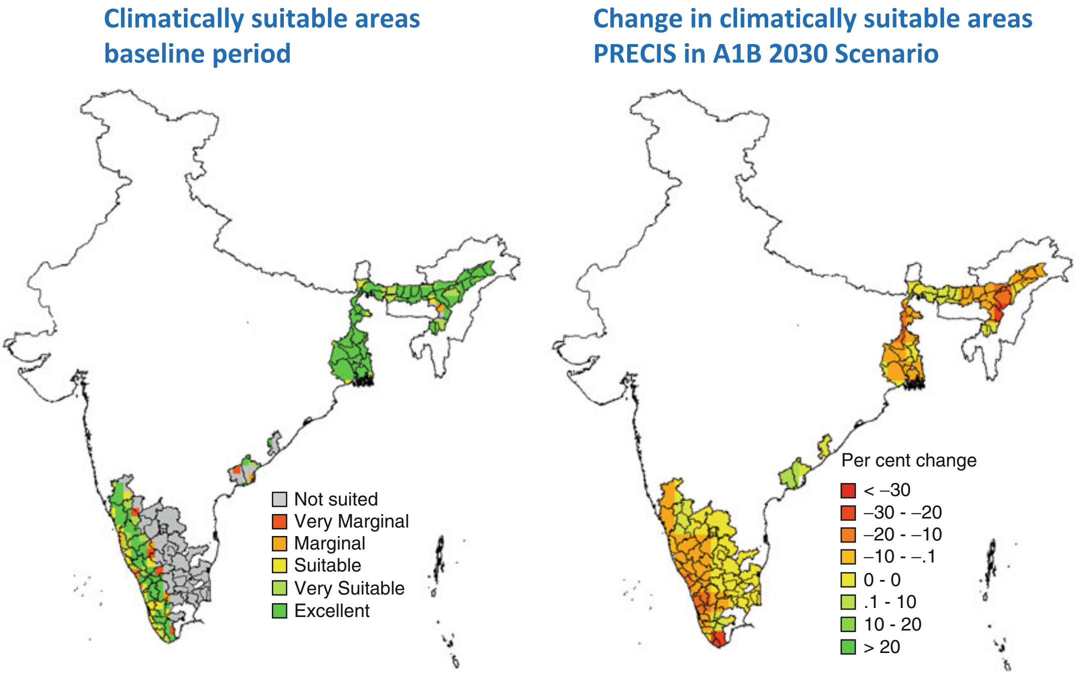

Fig. 3.5 Change in climatic suitability of regions for cultivation of areca nut in PRECIS A1b 2030 scenario

risks (to address the weather extremes). For the first one, crop improvement strategies such as development of 'adverse-climate tolerant varieties' or 'environmentally resilient varieties' form the core activity apart from regional infrastructure development for horticulture sector and policy support. The crop management through 'low-carbon' agronomic adaptation and improved resource use efficiency becomes important for addressing the immediate climatic risks (weather extremes). Some of such simple but effective adaptation strategies include change in sowing dates, management of plant architecture (in perennial crops), use of efficient technologies like drip irrigation, soil and moisture conservation measures, fertilizer management through fertigation, change of crop/alternate crop, increase in input use efficiency, pre- and post-harvest management of economic produce cannot only minimize the losses but also increase the positive impacts of climate change. Such adaptation strategies at regional level were worked out for managing coconut plantations. The assessment of potential adaptation gains indicated not only reduction in negative impacts of climate change but also to harness the positive impacts leading to overall improvement in coconut production in 2030 scenario. These adaptation strategies included improved planting material, improved input use efficiency through fertigation/drip irrigation, soil moisture conservation and input management. In fact, the analysis showed that adoption of such management strategies in all coconut plantations in India can dramatically increase the production even now.

3.9 Assessing Mitigation Potential in Horticulture

Mitigation is referred to the process in which the emission of greenhouse gases is reduced or they are sequestered. Improved agronomic practices for enhanced nutrient (nitrogen, inorganics and organics) use efficiency, water use efficiency for reduction of GHGs and eco-friendly disease and pest management strategies also form mitigation options. The models also help in quantification of GHG mitigation through adoption of technologies. However, there is a need to quantify the GHG emissions from all practices before tagging any technology as ‘green’ or ‘low-carbon’ technology. Models also need to be calibrated and validated for this purpose before doing for large-scale analysis. Linking to GIS and remote-sensing data also offers immense scope for regional estimations of GHG emissions.

Perennial horticultural crops, such as plantations, fruit trees and tree spices can be potential candidates for carbon sequestration potential. Even though currently most of these do not fall under Clean Development Mechanism or under carbon trade, there is a lot of scope for these tree species to be used for carbon sequestration and climate regulation. Studies conducted on coconut plantations indicated that annual carbon sequestration in coconut above ground biomass varied from 15 to 35 Mg CO_2 $ha^{-1}year^{-1}$ depending on cultivar, agroclimatic zone, soil type and management. It is also estimated that 2–3 Mg CO_2 $ha^{-1}year^{-1}$ is stocked into stem (Naresh Kumar 2009). Cocoa-areca nut also is a good system for carbon sequestration with a potential to sequester 5–7 Mg CO_2 $ha^{-1}year^{-1}$ (Naresh Kumar 2009; Balasimha and Naresh Kumar 2009). More information needs to be generated for perennial horticultural systems. Using InfoCrop-coconut simulation model, the carbon sequestration potential of coconut plantations at regional scale was also carried out (Naresh Kumar 2009).

3.10 Quantification of Ecosystem Services

Horticultural crops in general and plantation crops in particular provide several ecosystem services. These ecological goods include carbon sequestration, biodiversity preservation, microclimate regulation, nutrient recycling and water and air purification. Though quantification of these requires field level studies, the economic evaluation is done using the models such as INVEST and TOA. However, in India the quantification of ecosystem services is scarce or very limited. New initiatives in research are needed in this area as well.

3.11 Uses of Crop Models for Managing Horticulture

A better informed crop management can significantly reduce the yield loss. There is an urgent need for decision support system (DSS) for better management of agriculture at farm and regional level for a sustainable climate resilient crop production. Since a farmer needs answers to several questions related to crop production and marketing (Fig. 3.6), crop models are of immense use not only from climate change perspective but also from crop management point of view.

The major applications of crop simulation models include:

1. Crop management
2. Environmental characterization and agro-ecological zoning
3. Estimating potential production and yield gap analysis
4. Strategic and anticipatory decision making
5. Developing breeding strategies
6. Crop potential zones for land use planning
7. Indoor crop management, hi-tech horticulture
8. Crop insurance
9. Weather-based horti-advisory
10. Research priority setting
11. Local and regional planning
12. Defining research priorities
13. Technology transfer
14. Policy support

Crop modelling becomes particularly important in research and development of perennial plantation crops, since it takes a lot of time for conducting research experiments. The lag period for recovery of plantations in the event of prolonged stress such as droughts is also very long, and crop modelling can act as a decision support system for managing the plantations. As any approach, simulation modelling also has limitations and uncertainties attached to it. Hence, use of ensemble of models, model integration, becomes important. Use of more than one strategy and coupling of strategies provide more robust information and assessments.

Not only the growth simulation models but the plant architectural models play an important role in managing the horticultural crops. Plant

Fig. 3.6 Farmer seeks answers to several questions, primarily issues related to his farm and produce management

architecture is modelled for grapes, palms, apple, olives, etc., using the ARCHIMED, ALEA platforms. Exploitation of models and modelling techniques for managing horticultural crops in changing climates is essential for integrating the scientific, technological and socioeconomic knowledge in pursuit of minimizing the adverse impacts and maximizing the potential benefits of climate change.

3.12 Research Thrusts for Horticultural Crops in Climate Change Watershed

Since very little information is available from India in horticultural crops with respect to response of crops to elevated CO_2, temperature and extreme events, there is a need to conduct focused research to generate information for modelling impacts of climate change and derive adaptation and mitigation strategies. Some of the thrust areas for research include:

- Development of crop coefficients for growth and development
- Quantification of sensitivity and sensitive stages of crops to weather aberrations
- Quantification of impacts of elevated CO_2 and change in temperature and rainfall on growth, development, yield and quality of horticultural crops
- Monitoring the phenology of perennial crops under changing climates, etc.
- Development of crop simulation models for horticultural crops
- Development of eco-friendly low-carbon adaptation technologies and their deployment in large areas
- Assessment of the impacts at regional level for more horticultural crops
- Assessment of potential adaptation strategies (for evolving targeted no regret low-carbon adaptation strategies)
- Quantification of carbon sequestration potential of perennial horticultural systems
- Weather-based pest-forecasting system
- Location-specific weather forecast based on eco-friendly horti-advisory and real-time crop monitoring
- DSS for horti-advisory and use of ICT for bridging research-stakeholder communication (Fig. 3.7)
- Quantification of ecological goods and ecosystem services provided by various sectors of horticulture

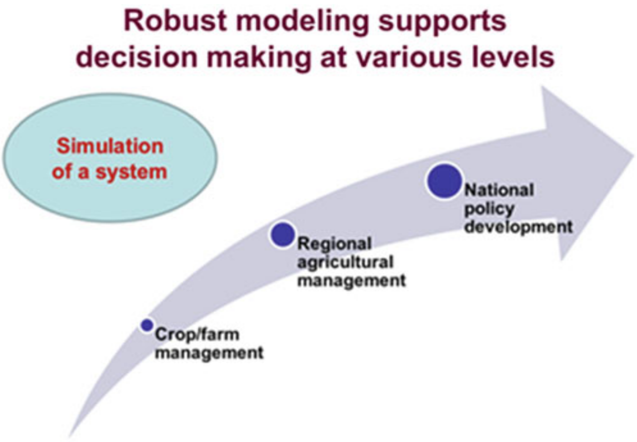

Fig. 3.7 Application modelling information at different levels of decision making

There is a lot of scope to improve the institutional support systems such as weather-based agro-advisory, input delivery system, development of new land use patterns, community storage facilities for horticultural perishable produce, community-based natural resource conservation and training farmers for adapting appropriate technology to reduce the climate-related stress on crops. All these measures can make the horticultural farmer more resilient to climate change.

3.13 Conclusion

Horticultural crops deserve more attention for quantification of impact of climate change and climatic risks and for deriving adaptation strategies as they offer scope for improvement of household livelihood and income and therefore help in developing resilience to climatic risks. In order to do so, there is an urgent need to have impact assessments carried out and develop the adaptation strategies. Crop simulation modelling can help in managing horticulture in a better way in changing climates and to manage climatic risks. There is a need to carry out focused studies for quantifying the crop response to weather extremes, CO_2, temperature and rainfall. The focus should also be on development of eco-friendly, low-carbon adaptation technologies and quantify the mitigation potential of horticultural crops. Since scope for use of simulation models is immense, developing simulation models for horticultural crops should be a priority area for not only enabling the regional impact, adaptation and vulnerability analysis but also for better utilization of research and developmental efforts. Strengthening the research efforts and initiating the focused research on climate change-related issues in horticultural crops and policy support will help in making the Indian horticulture climate resilient.

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4

Impact of Abiotic Stresses on Horticulture and Strategies for Mitigation in Northeastern India

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and Ram Kishor Patel

Abstract

The northeastern region is considered to be the richest reservoir of genetic variability of large number of horticultural crops. Changes in weather parameters have profound impacts on the livelihood of people and their ecosystem as whole. These problems can be mitigated by the selection of suitable cultivars of fruits, vegetables and spices crops which have the potential to grow under diverse weather conditions. Protected cultivation of high-value vegetable crops like tomato, capsicum and cucumber provides means for round-the-year production with protection against low temperature and heavy rains. Drip irrigation is the most suitable system for efficient utilization of water especially for the horticultural crops. The appropriate techniques to overcome the impact of climate change are necessary to protect our biodiversity and for feeding the fast-growing population. Awareness and educational programmes for the growers, modification of present horticultural practices and greater use of greenhouse technology are some of the solutions to minimize the effect of climate change.

4.1 Introduction

The northeastern region of India, comprising of eight states, viz. Assam, Arunachal Pradesh, Meghalaya, Manipur, Mizoram, Nagaland, Tripura and Sikkim, falls under the high-rainfall zone and the climate ranges from subtropical to alpine. The area is extended from 88° to 97°E longitude and 22° to 29. 30°N latitude with a total geographical area of about 255,083 sq Km. It comprises of about 35% of area under plains and the remaining 65% area under hills. The altitude varies from the low-lying plains of Brahmaputra (20 m) to around 6,000 m in parts of Arunachal Pradesh. The region is characterized by difficult terrain, wide variations in slopes and altitudes, land ownership (community) systems and indigenous cultivation practices. Northeastern India has a total cropped area of 5.3 million ha supporting a population of around 39 million. Out of 4.4 million ha net sown area, roughly 1.4 million ha

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lies in hilly subregion and around 1.3 million ha area is affected by soil erosion problem. About 0.5 million ha area is under shifting cultivation in the region.

The northeastern region is considered to be the richest reservoir of genetic variability of large number of horticultural crops. The fruits grown in this region ranged from tropical and subtropical (citrus, banana, papaya, pineapple, guava, passion fruit) to temperate types (apple, pear, peach, plum, strawberry, kiwifruits, nuts). Apart from these, there are certain underutilized fruit crops, viz. *Prunus nepalensis*, *Elaeagnus latifolia, Phyllanthus acidus* and *Myrica spp.* which are grown at a large scale in some or the other parts of the region. The enormous diversity makes the region a gene pool for the varietal improvement of many vegetable and spices crops. The important vegetable and spices crops grown in the region are tomato, chilli, potato, brinjal, turmeric, ginger, cucurbitaceous crops, cole crops, leguminous and leafy vegetables, tuber and rhizomatous crops and lesser-known vegetables like tree bean, tree tomato, drumstick, chow-chow, kartoli and *Flemingia vestita*.

4.2 Horticultural Scenario

Horticulture is the backbone of agriculture sector of northeast India and its potentiality is yet to be harnessed to its full extent. The total area under horticultural crops (fruits & vegetables) during 2009–2010 in the region was around 0.7735 million ha which is around 5.40% of the total area under fruits and vegetables in the country. From this area, the region produces about 9.9082 million t of fruits and vegetables with a productivity of 12.81 t/ha against the national productivity of 14.34 t/ha (Tables 4.1, 4.2 and 4.3). The area under various fruits and vegetable crops in the northeastern region during 2009–2010 was about 0.3677 and 0.4058 million ha with an annual production of 3.40 and 6.50 million t having the productivity of 9.26 and 16.03 t/ha, respectively (Anon 2011).

4.3 Projected Climate Change and Its Impact on Horticultural Crops in 2030s

4.3.1 Projected Changes in Climatic Factors

4.3.1.1 Changes in Temperature

The surface air temperature in this region is projected to rise from 25.8°C to 26.8°C in the 2030s, with a standard deviation ranging from 0.8°C to 0.9°C (Indian Network for Climate Change Assessment, INCCA-2010). The rise in temperature with respect to 1970s is in the range of 1.8–2.1°C. Minimum temperatures are likely to rise from 1°C to 2.5°C, and maximum temperatures may rise by 1–3.5°C. The Himalayan region is likely to remain unaffected, but changes in thermal stress are expected in most parts of northeastern region. Temperature-humidity index (THI) has been used to represent thermal stress due to the combined effects of air temperature and humidity. THI is used as a weather safety index to monitor heat-stress-related losses (National Research Council 1971). In this region, the THI is likely to increase between April and October months with THI > 80.

4.3.1.2 Changes in Precipitation

The mean annual rainfall is projected to vary from a minimum of 940 ± 149 mm to a maximum of 1330 ± 174.5 mm. The increase in 2030s, with respect to 1970s, is of the order of 0.3–3%. In northeastern region, the number of rainy days is likely to decrease by 1–10 days. Intensity of rainfall in the region is likely to increase by 1–6 mm/day. The trend in precipitation in northeastern region exhibits considerable spatial variability in water yield in the 2030s but is in line with the projected patterns of precipitation and evapotranspiration. As compared to 1970s, precipitation in 2030s in northern parts of the region shows a reduction that varies from 3% in the northwestern part of the region to about 12% in the northeastern part. The central portion of

Table 4.1 Area and production of fruits during 1999–2010

	Area (000’ha)				Production (000’t)			
States	1999–2000	2006–2007	2008–2009	2009–2010	1999–2000	2006–2007	2008–2009	2009–2010
Arunachal Pradesh	44.1	57.5	57.6	72.0	93.1	107.9	108.0	107.9
Assam	106.1	137.0	105.2	117.3	1249.5	1572.4	1574.8	1575.5
Manipur	25.6	34.0	42.4	38.4	118.1	229.1	341.9	281.9
Meghalaya	26.9	26.0	32.9	32.9	223.3	216.7	294.8	294.8
Mizoram	13.0	22.3	34.1	27.1	40.7	219.6	123.1	328.3
Nagaland	19.4	21.0	18.2	30.8	232.3	147.3	151.3	223.7
Sikkim	5.9	09.0	10.5	12.2	8.6	13.4	15.7	18.5
Tripura	30.4	33.6	36.5	36.9	372.1	525.6	477.2	573.8
Northeast	270.4	340.4	337.4	367.7	2337.7	3032.0	3086.7	3404.4
India	3796.8	5806.5	6100.9	6329.2	45496.0	62858.0	68465.5	71515.5

Source: Anon 2011

Table 4.2 Area and production of vegetables during 1999–2010

	Area (000’ha)				Production (000’t)			
States	1999–2000	2006–2007	2008–2009	2009–2010	1999–2000	2006–2007	2008–2009	2009–2010
Arunachal Pradesh	16.7	23.7	23.8	4.2	80.5	110.0	110.0	38.5
Assam	223.2	354.0	240.1	255.2	2074.1	4800.8	2916.7	4569.9
Manipur	8.0	10.3	16.6	19.9	53.2	91.8	174.3	221.8
Meghalaya	41.8	39.4	44.3	44.3	412.2	380.7	415.8	415.8
Mizoram	6.8	1.2	14.4	10.6	49.6	37.3	114.4	179.1
Nagaland	19.3	15.2	10.4	10.4	188.4	96.8	78.3	78.3
Sikkim	12.0	17.8	21.5	28.7	54.0	80.8	98.0	147.7
Tripura	32.0	33.6	25.6	32.5	358.5	423.5	294.7	446.9
Northeast	359.8	495.2	396.6	405.8	3270.5	6021.7	4202.2	6098.0
India	5515.2	7727.8	7980.7	7984.8	75074.6	122255.9	129076.8	133737.6

Source: Anon 2011

Table 4.3 Area and production of spices and plantation crops during 2009–2010

	Spices		Plantation crops	
States	Area (000’ha)	Production (000’t)	Area (000’ha)	Production (000’t)
Arunachal Pradesh	7.6	43.3	–	–
Assam	27.4	18.6	88.8	163.7
Manipur	9.0	7.8	–	–
Meghalaya	17.4	72.0	12.4	17.1
Mizoram	22.7	80.6	6.6	8.2
Nagaland	7.2	38.6	1.1	1.6
Sikkim	26.6	41.7	–	–
Tripura	4.0	12.1	10.2	16.4
Northeast	121.9	314.7	433.8	207.0
India	2463.7	4016.0	3246.6	11928.2

Source: Anon 2011

the northeast shows an increase in precipitation varying from zero to as much as 25%. However, the majority of the northeastern region, except for Mizoram, Tripura, Manipur and Assam, shows an increase in evapotranspiration in 2030s. As a result, the reduction in water yield for Arunachal Pradesh is up to about 20%. There is an increase in the water yield to up to about 40% in Assam and Manipur.

4.3.1.3 Changes in Evapotranspiration (ET)

Majority of the northeastern region shows an increase in ET during 2030s scenario. It is interesting to note that even those parts of Arunachal Pradesh that were showing a decrease in precipitation show an increase in ET.

This can only be explained by the occurrence of higher temperatures that enhance the evaporative force. However, the increase in ET ranges from a small fraction to about 20%. The reduction in ET in the southern portion is only marginal. The trend in water yield in the northeastern region is similar to the precipitation trend. The areas that have shown less increase in precipitation show a correspondingly low water yield. The reduction in water yield in Arunachal Pradesh is up to about 20%. An increase in water yield is seen in Assam and Manipur, and the magnitude is up to about 40%.

Northeastern region also shows a considerable increase in sediment yield for majority of the areas which are expected to see an increase in precipitation. The increase in the sediment yield of the region is up to 25%. There are a few areas of Arunachal Pradesh that are expected to receive less rainfall and show a reduction in sediment yield of up to 25% under the 2030s scenario.

4.3.2 Impacts of Climate Change on Horticulture

4.3.2.1 Production System

Little work has been done with respect to impact of climate change on horticulture. The simulation analysis indicates that the potato yields are likely to be marginally benefited up to 5% in upper parts of NE region due to climate change influence, but in the central part, the yields are projected to reduce by about 4%, while in the southern parts of NE region, the negative impacts will be much higher (INCCA 2010).

Wurr et al. (1996) reported that by increasing the ambient temperature approximately 4°C above normal gave consistently earlier maturity of lettuce, delayed cauliflower curd initiation by up to 49 days and increased the final number of leaves in cauliflower by 36. Crops like lettuce, celery, cauliflower and kiwi grown under high temperatures matured earlier with lower harvest index than the same crops grown under low temperatures. The increased temperatures in Sambalpur, India, have delayed the onset of winter. As a consequence, cauliflower yields have dropped significantly (Pani 2008). Where growers commonly harvested 1 kg heads, inflorescences are now smaller, weighing 0.25–0.30 kg each. Reductions in yield drive up production costs, an effect also observed in tomato, radish and other native Indian vegetable crops.

Rosenzweig et al. (1996) reported decline in yield of orange cultivar Valencia due to excessive heat during the winter which might be counteracted by the rise in the CO_2 in the atmosphere; however, fall in potato production with increased CO_2 and changes in planting date were estimated to have minimum-compensating impacts on simulated potato yields. Moderately high temperatures do not appear to limit photosynthesis and dry matter production in potato (Reynolds et al. 1990; Wolf et al. 1990b; Midmore and Prange 1992), but partitioning of photosynthate away from leaves and towards tubers is likely to be decreased under these conditions (Krauss and Marschner 1984; Wolf et al. 1990a; Basu and Minhas 1991). Nonetheless, the potato contains considerable genetic variability and plasticity, providing a basis for optimism with respect to adaptation to warmer climates (Levy 1986a, b; Manrique 1989; Reynolds and Ewing 1989a, b).

Temperate horticultural crops in Himachal Pradesh were the worst hit during heat wave in summer, 2004. Flowering of apple is advanced by 15 days under high-temperature scenario. A large-scale flower drop was seen in April due to acute moisture stress. Heavy rainfall during the second fortnight of April accomplished by sharp fall in temperature results in poor fruit-set. The optimum temperature for fruit blossom and fruit-set in apple is 24°C, while the region experienced 26°C for 17 days. In contrast, some parts of Jammu, Punjab, Haryana, Himalchal Pradesh, Bihar, Uttar Pradesh and northeastern states experienced the unprecedented cold wave during 2002–2003. The crop yield loss varied between 10% and 100% in the horticultural crops like mango; the fruit size and quality were adversely affected in many crops. However, temperate crops like apple, plum and cherry gave higher yield due to extended chilling. The damage was more in low-lying area where cold air settled and remains for a longer time in ground (Sharma et al. 2004). Awasthi et al. (1986) have indicated that irregular bearing behaviour of Starking Delicious apple is largely influenced by climatic conditions. The rains and hails during flowering adversely affect the fruit-set, whereas moderate temperature of 20°C with relatively low rains during flowering results in good fruit-set.

Field vegetable production systems contribute to climate change through emission of the greenhouse gases CO_2 and N_2O. Since field vegetables like all other plants fix atmospheric CO_2, the net emission of CO_2 from vegetable production systems will be insignificant, especially when high-yielding varieties are used, crop residues are not removed from the field, inorganic fertilizers are replaced by organic manures and reduced tillage is applied. N_2O emission can be reduced by increasing the efficiency of N use by the vegetables.

In tomato, at high temperature, seedlings grow faster and the differentiation and development of flower is also promoted. However, the flower set decreases due to flower abscission, malformed flower and pollen sterility. Similarly, in cucumber high temperatures inhibit flower differentiation and development and result in smaller ovaries in pistillate and bisexual flowers. However, in potato almost no tubers form if night temperatures exceed 20°C. Floral differentiation of strawberry is also strongly affected by temperature and photoperiod. At 16–26°C flower buds form under short-day photoperiod and no flower buds form above 27°C. Therefore, high temperatures will delay floral formation and result in small fruits (Johkan et al. 2011).

4.3.2.2 Quality Aspects

Production and quality of fresh fruit and vegetable crops can be directly and indirectly affected by high temperatures and exposure to elevated levels of carbon dioxide and ozone. Chan et al. (1981) and Picton and Grierson (1988) observed that high-temperature stresses inhibited ethylene production and cell wall softening in papaya and tomato fruits. On the other hand, cucumber fruits showed increased tolerance to high-temperature stress (32.5°C) with no change in vitro ACC oxidase activity (Chan and Linse 1989). Tip burn in lettuce is a disorder normally associated with high temperatures in the field which can cause soft rot development during postharvest. Black heart in potato occurs during excessively hot weather in saturated soil. The symptoms usually occur in the centre of the tuber as dark-grey to black discoloration. The translucent fruit flesh in pineapple appears due to high temperature. Exposure of tomato fruits to temperatures above 30°C suppresses many of the parameters of normal fruit ripening including colour development, softening, respiration rate and ethylene production (Buescher 1979; Hicks et al. 1983).

Hogy and Fangmeier (2009) studied the effect of high CO_2 concentrations on the physical and chemical quality of potato tubers. They observed that increase in atmospheric CO_2 (50% higher) increased tuber malformation in approximately 63%, resulting in poor processing quality, and a trend towards lower tuber greening (around 12%). Higher CO_2 levels (550 µmol CO_2mol^{-1}) increased the occurrence of common scab by 134%, but no significant changes in dry matter content and specific gravity were observed. Prolonged exposure to CO_2 concentrations could induce higher incidences of tuber malformation and increased levels of sugars in potato and diminished protein and mineral contents, leading to loss of nutritional and sensory quality.

Exposure of crops to ozone changes the carbon transport system in the underground storage organs (e.g. roots, tubers, bulbs). Normally, carbon gets accumulated in the form of starch and sugars, both of which are important quality parameters in both fresh and processed crops. If carbon transport to these structures is restricted, there is great potential to lower quality in such important crops like potatoes, sweet potatoes, carrots, onions and garlic (Felzer et al. 2007). High concentrations of atmospheric ozone can potentially cause reduction in the photosynthetic process, growth and biomass accumulation. Ozone-enriched atmospheres increased vitamin C content and decreased emissions of volatile esters from strawberries. Tomatoes exposed to ozone concentrations ranging from 0.005 to 1.0 μmol mol^{-1} had a transient increase in β-carotene, lutein and lycopene contents (Moretti et al. 2010).

Due to heavy rain, the loss of essential nutrients like Ca and Mg is a common problem with the toxicity of heavy metals. Recently, the emphasis has been placed on N and Ca, the nutrients most closely associated with fruit quality. Possible responses include precision horticulture with more targeted nutrient management. This in turn will require improved understanding of application efficiencies and the timing and magnitude of nutrient demand in order to synchronize fertilization more closely with plant requirements. Higher concentrations of atmospheric carbon dioxide (CO_2), for example, may actually benefit potatoes as increased CO_2 stimulates the development of underground biomass in potato plants, with tuber weight and number both increasing significantly. Higher levels of atmospheric ozone (O_3) also seem to benefit the crop, resulting in more of the antioxidant ascorbic acid in tubers.

4.3.2.3 Pest and Diseases

Higher rainfall and humidity is congenial for increasing disease intensity in potato, such as late blight (*Phytophthora infestans*), especially when combined with longer growing seasons. Bacterial wilt may also increase as the climate becomes warmer and wetter, and potato pests, including disease-carrying aphids, will survive at higher altitudes. With the rise in temperature and humidity, the new biotype of diseases will emerge which is tolerant to varied climatic conditions. Soilborne disease like bacterial wilt (*Ralstonia solanacarum*) will be more problematic which can grow up to 40°C. Under future climate change conditions, treatments in growth chamber experiments on four major diseases of chilli pepper include two fungal diseases, anthracnose (*Colletotrichum acutatum*) and Phytophthora blight (*Phytophthora capsici*), and two bacterial diseases, bacterial wilt (*Ralstonia solanacearum*) and bacterial spot (*Xanthomonas campestris* pv. *vesicatoria*) was recorded. Treatments with elevated CO_2 and temperature were maintained at 720 ±20 ppm CO_2 and 30 ± 0.5°C, whereas ambient conditions were maintained at 420 ±20 ppm CO_2 and 25 ± 0.5°C. Pepper seedlings or fruits were infected with each pathogen, and then the disease progress was evaluated in the growth chambers. According to paired *t*-test analyses, incidence of bacterial wilt and spot was increased on pepper by 24% and 25%, respectively. Intensity of anthracnose got decreased while intensity of Phytophthora blight slightly increased, but the fungal diseases were not statistically significant, suggesting that bacterial diseases on chilli pepper will likely to be more serious in the future (Jeong and Sung 2010).

4.4 Silent Observations on Horticultural Crops Related to Climate Change in Meghalaya

- The heavy rainfall from April to October causes heavy soil erosion and nutrient loss as well as results in manifestation of different types of insect-pest and diseases, and as a result, the crop productivity is reduced to a great extent.
- The long dry spell from November to March results in moisture stress in many of the horticultural crops, and because of this, the young orchard of *Khasi* mandarin has started declining in entire NEH Region.
- During last 3–4 years, the incidence of fruit flies has become a serious concern in peach and guava. Control of fruit flies by appropriate means is a major challenge among the entomologists.
- In underutilized crops, powdery mildew and blight are new record in *Prunus nepalensis,* which was never noticed until 2–3 years back.

- Cabbage butterfly is another serious problem in cole crops during February–April, which was not recorded earlier.
- The late blight becomes a serious problem in tomato and potato during summer season (April–June) due to low temperature and heavy rains which provide congenial environment for disease development.

4.5 Mitigation Measures

4.5.1 Varietal Intervention

Turmeric: Megha Turmeric-1, a clonal selection from the local genotype Lakadong, is tolerant to leaf blotch and leaf spot. It matures in 300–315 days having an average yield of 27–30 t/ha. It has 6.8% curcumin and dry matter content of 20–22%. *Tomato*: Megha Tomato-3 which is tolerant to cold and bacterial wilt disease. Fruits are round, smooth with uniform colour development. The average yield of the variety is 45–55 t/ha with a TSS of 4.5–5.5°Brix and shelf life of 15–18 days at ambient condition.

Dolichos Bean: RCDL-10 a photo insensitive line can be used for the production during summer season and can also be used as a parental line for the varietal development.

Potato: Kufri Megha and Kufri Kanchan have been identified as resistant to late blight which is a major problem of the region.

Low-Chilling Peach Cultivars: Flordasun, Shan-e-Punjab and Partap have been found to be suitable for the region.

4.5.1.1 Technological Interventions

Cropping Sequence in Low-Cost Polyhouse

The experiment was undertaken to standardize a crop cycle for year-round production of vegetables under low-cost polyhouse.

In Manipur valley, King chilli (October–April) → Cucurbits + Okra (May–September) → Capsicum + Beans (October–January) → Lettuce + Chilli (February–May) → Cowpea + Palak + Tomato (June–September) were found to be the best combinations. After second year, green manure crops should be grown for one season to enhance the soil fertility status. In this cycle, multiple crops have been selected to minimize the risk of crop loss. Solanaceous crops were not grown on the same area under polyhouse. If the night temperature in winter season goes below 4–5°C, charcoal may be burnt inside the polyhouse particularly at night period to maintain the inside temperature.

In Meghalaya, despite congenial temperature during rainy season, tomato could not be grown under open condition due to heavy disease and pest infestation. However, tomato can be grown successfully under low-cost polyhouse during May–September with proper crop management. Cucumber is identified as the best crop (immediately after tomato) during September–January. Capsicum followed by cucumber can be grown during January–May. Liming is essential for maintaining the optimum soil reaction (pH 5.5-6.0). Tomato cvs. Megha Tomato-1, Megha Tomato-2 and Megha Tomato-3, Cucumber cvs. Japanese Long Green and Kalyanpur Hara and capsicum cvs. California Wonder, Bharat and Indira were found suitable for low-cost polyhouse.

Canopy Management: Effect of pruning severity and time on early flowering of peach. Among the low-chilling varieties, Flordasun, Shan-e-Punjab and Partap (TA-170) were found suitable for mid-hill conditions of northeast. Under mid-hills of Meghalaya, the ripening period coincides with early rains in the month of May. High infestation of fruit flies and brown rot during that time mars the eating quality, marketability and storage life of fruits. Ten-year-old grafted Peach cv. Partap (TA-170) trees were pruned on 30th October, 15th November and 30th November (normal pruning time) with 50% and 70% intensity. It was noticed that earliest fruits were harvested from 10th to 20th April (15 days earlier) in 30th October pruning with 50% pruning severity as compared to normal pruning date where harvesting lasted up to 15th May. The yield, fruit size and quality were at par with normal pruning schedule. Therefore, last week of October may be recommended for pruning of low-chilling peach for early harvest of quality fruit.

4.5.1.2 Off-Season Production of Strawberry

Strawberry cv. Ofra can be produced 30–35 days earlier than normal period, when planted in low tunnels of 50% shade net (4.0 m × 0.90 m × 0.75 cm.) in the month of July or August, and the period of fruit availability may be extended by 47 days from normal when planted in the month of November under UV-stabilized polythene tunnels (200 gauge). During the study period, normal fruiting period under open condition was 18th January to15th March.

4.6 Future Strategies

In view of these problems, horticulturists will have to play a significant role in the climate change scenario and proper strategies have to be envisaged for saving horticulture from future turmoil:

- Adoption of sustainable agriculture development pathway, besides using renewable energy, forest and water conservation, reforestation, etc.
- Conservation and utilization of horticultural genetic resources.
- Identification and development of cultivars tolerant to high temperature, moisture stress and resistant to pests and diseases for various altitudes.
- Water harvesting through pond, jalkund and its judicious utilization in the form of drip, mist and sprinkler to deal with the drought conditions including adoption of soil moisture conservation practices like mulching.
- Hi-tech horticulture is to be adopted in an intensive way. It is necessary that selection of plant species/cultivars is to be considered keeping in view the effects of climate change.
- Monitoring and management of new pathogens/insect-pests.
- Cultivation of parthenocarpy cultivars, use of auxin for parthenocarpy fruits set in tomato, egg plant and cucumber.
- Grafting of the scion on root stock with high drought, heat and salt stress tolerance can increase the growth and yield of the crops.
- Awareness and educational programmes for the growers, modification of present horticultural practices and greater use of green house technology are some of the solutions to minimize the effect of climate change.

4.7 Conclusion

Climate change scenario becomes a serious concern for the global agriculture; northeastern region of India is one of the major biodiversity hot spot and origin of many important species in which changes in weather parameters have profound impact on the livelihood of people and their ecosystem as whole. These impacts can be mitigated by the selection of fruit crops and cultivar, like low-chilling peach cultivar such as Shan-e-Punjab and Flordasun; citrus species like *Khasi* mandarin, Assam lemon, passion fruit and strawberry in mid-hills; apple, pear and plum at higher altitude; and in plains like guava, banana and papaya. Apart from these, there are certain underutilized fruit crops which can be grown at a large scale in some or the other part of the regions like *Prunus nepalensis*, *Elaeagnus latifolia, Phyllanthus acidus and Myrica spp*. The important vegetable and spices crops which have the potential to grow under varied weather conditions, for example, tomato cold and drought-tolerant cultivar Megha Tomato-3, anthracnose-tolerant chilli cultivar Kashi Anmol, cucurbitaceous crops (chow-chow, bottle gourd, ash gourd and pumpkin), potato (Kufri Megha) cole crops, leguminous (French bean, Dolichos bean and cow pea) and leafy vegetables, tuber and rhizomatous crops and lesser-known vegetables like tree bean, tree tomato, drumstick, kartoli and *Flemingia vestita* and spices like turmeric and ginger. Protected cultivation of high-value vegetable crops like, tomato, capsicum and cucumber provides means for round-the-year production with the protection against low temperature and heavy rains. The drip irrigation is the most suitable system for efficient utilization of water especially for the horticultural crops. Fruit and vegetable crops also have the potential in sequestration of CO_2 from atmosphere, which alone contributes to about 60% of global warming. The appropriate techniques to mitigate the impacts of climate change are necessary to conserve our biodiversity and for feeding our fast-growing population. For this, diversification towards horticultural crops and suitable blending with others like agronomic crops, animal husbandry, fish and pig together is necessary to get sustainable family income and to conserve natural resources.

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5 Impact, Adaptation and Mitigation Strategies for Climate Resilient Banana Production

Iyyakutty Ravi and Mohamed Mohamed Mustaffa

Abstract

Globally, bananas occupy fourth most important commodity after rice, wheat and corn. In India, banana is grown in the regions from the humid tropics to humid subtropics and semiarid tropics. Banana is a plant of the tropics and subtropics, requiring hot and humid climate. The areas which experience both water shortage and high temperature may pose further problem, in the face of changing climate, in growing traditional banana cultivars. The pests and disease are another area of concern. The banana leaf spot disease may spread and become serious towards northern belt of India as temperature favours this disease development. In Jalgaon, traditional banana growing region of Maharashtra state, India, the leaf spot disease was not observed earlier, and but now, this devastating disease and cucumber mosaic virus disease started appearing. These new developments may be due to climate change. Adaptation strategies through changes in farming practices, cropping patterns and use of new technologies will help to ease the negative impact of climate change.

5.1 Introduction

Climate change will lead to higher temperatures, altered precipitation and higher levels of atmospheric CO_2 (IPCC 1990). Asia faces a heightened risk of either flooding or severe drought due to global warming, and 30% of plant and animal species will be vulnerable to extinction if global temperatures rose by 1.5–2.5°C (IPCC 2007). By midcentury, annual average river run-off and water availability are projected to increase by 10–40% at higher latitudes and in some wet tropical areas, and water availability will decrease by 10–30% in some dry regions at midlatitudes and in the dry tropics, some of which are presently water-stressed areas.

Only 3% of the earth's water resources is freshwater and 1% is available for human activity, including agriculture. The amount of water required for crop production varies depending on

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soil conditions, crop variety and temperature. Imbalances between water availability and demand will most likely be exacerbated by climate change, and, like access to energy, water management is becoming one of the main geostrategic challenges of the twenty-first century (Anonymous 2010).

5.2 Banana Production in India

Globally, bananas (*Musa* spp., AA, AB and AAA group), plantain (AAB) and cooking banana (ABB) occupy fourth most important commodity after rice, wheat and corn. Basically, bananas are water-loving crop; and large areas of the bananas are grown along the river basins, viz. Gangetic Plains of Bihar, around Godavari river basin in Andhra Pradesh, areas around Tapti River in Maharashtra and Cauvery Delta regions of Tamil Nadu and in other areas where water sources have been created. It is grown in more than 130 countries across the world in an area of 8.25 million ha producing 97.38 million t of banana and plantain. India is the largest producer of banana in the world, contributing 24% to the global production with a total production of 26.90 million t from an area of 0.77 million ha. Among the horticultural crops, contribution of banana to agricultural Gross Domestic Product (GDP) is the highest to the tune of 1.99% (Singh 2007).

5.3 Climate Requirements for Banana

The banana is a plant of the tropics and subtropics, requiring hot and humid climate. In India, banana is grown in the regions from the humid tropics to humid subtropics and semiarid tropics and from the sea level up to an elevation of 2,000 MSL.

The most suitable climate is the one with warm moist weather throughout the year without strong winds. The favourable factors determining its distributions are rainfall in excess of 100 mm per month (Simmonds 1966) and a temperature range of 10–40°C with an optimum between 25°C and 30°C and a mean minimum temperature of 15.5°C. The rate of appearance of new leaves and rate of fruit growth are largely governed by temperature. Factors that operate against extension of its cultivation are areas with long dry season, frost occurrence, cool winters, hot winds in summers and stormy or cyclonic winds. Broadly speaking, banana cultivation is widely practised in areas with 102-cm isohyet and 15.5°C (60°F) winter isotherms which roughly coincides with 30 ° latitude North and South of the equator. Based on the monthly mean climatic data of the area of banana cultivation, Simmonds (1966) selected rainfall of 100 mm and mean monthly temperature of 27°C as arbitrary limits and considered them satisfactory. Fairly good soil drainage is known to be an essential condition which favours growth of the banana crop.

5.3.1 Impact of Temperature on Banana Growth

Banana plant development is reflected at the rate in which new leaves are produced. While nutrient and water supply can influence the rate of appearance of new leaves, the dominant riding factor is temperature. The optimum temperature for leaf production and plant growth is 31.6°C and optimum, minimum and maximum temperature for other growth parameters are given in Table 5.1.

Leaf emergence stops below 10°C temperature. During the summer, each plant may produce 4 or 5 leaves a month, but in the winter, only about half a leaf a month (Turner 2003) is produced. A banana plant produces 40–50 leaves before flowering (Cavendish group). The rate of leaf production indicates the healthy status of the plant as well as the favourable climate. In a healthy banana plant, under favourable tropical conditions, a leaf is produced in 7–10 days interval in 'Dwarf Cavendish' bananas, but in winter, it takes 20 days for leaf production. The different stages of leaf unfurling are completed in 4 days in summer, while in winter, it takes about 14 days or more. Thus, winter is a time where not only leaf production is low but loss is great. The rate of leaf production increases significantly with increase in mean monthly temperature. The temperature has overriding effect on leaf production in different season (Turner 1971). Leaf production

Table 5.1 Minimum, optimum and maximum temperature required for various physiological processes for *Musa* spp. AAA cv. Williams

Variable	Minimum temp.(°C)	Optimum temp.(°C)	Maximum temp.(°C)	Ymax
Leaf area (m^2 week)	12.30	31.10	33.50	0.267
Leaf production ($week^{-1}$)	8.00	31.60	33.50	01.01
Relative leaf area growth rate ($week^{-1}$)	10.50	28.10	33.50	0.147
Dry weight increment (g $week^{-1}$)	11.50	21.20	39.20	42.90
Relative growth rate ($week^{-1}$)	7.30	22.40	38.20	00.19
Unit leaf rate (g m^{-2} $week^{-1}$)	11.50	17.70	32.70	05.30

Source: Turner and Lahav 1983

increases by one leaf per month for every 3.3–3.7°C rise in minimum or mean temperature from 10°C to 20°C or 13.5–25°C, respectively (Turner 1971; Robinson 1981).

In banana plants growing under cool conditions, the leaves are more upright, but under warmer conditions, they are more horizontal. The rate of plant development (for any given variety) is slower in the subtropics than in the tropics, and maximum yields occur, in the present climate, at latitudes between 15° and 20°. The optimum temperature for bunch development is about 10°C less than the optimum temperature for the rate of leaf appearance. For the 'Williams' (Cavendish group) variety, the optimum temperature for bunch growth is about 21°C or 22°C. Temperature has a big influence on the rate of fruit growth, thus use of bunch covers, which are thought to warm the fruit, increased the growth rate (Turner et al. 2007). Bunch covers also reduce the gradient of temperature across the bunch, and fruit from covered bunches is more uniform than that from uncovered bunches. High air temperatures (usually greater than 38°C) and bright sunshine are associated with sunburn damage on exposed fruit, especially on the top hands of the bunch. Sunburn can be avoided if a protective covering such as paper is placed between the fruit and the cover, or covers with a reflective coating on one side are used (Turner 2003).

Chilling symptoms on leaves are not seen immediately but it may take 2–4 days to appear. The chilling-injured lamina turns yellow and on the emerging leaf, especially in the most recently emerged part of the midrib may show brown areas which are water soaked underneath. On older leaves, the symptoms can be similar to potash deficiency symptoms. In late autumn and early winter, when the cold arrives, the effect on older leaves can be dramatic, especially if Sigatoka leaf spot and leaf speckle diseases have not been controlled. The older leaves break at the petiole, and 3 or 4 may hang as a skirt around the pseudostem. These leaves quickly turn yellow and die. Under cooler conditions, banana cannot maintain all its leaves and the older ones are lost (Turner 2003). Once temperatures drop below freezing, damage occurs quickly and a few hours later, the leaves and bunches become water soaked, blacken and die. Frost rarely kills the whole plant. It is usually only the exposed tissues which are damaged. Within a few days, the youngest leaf begins to emerge again and growth resumes. When plants are completely defoliated by frost, the formation of the bunch can be delayed and, if a bunch is already present in the pseudostem, the yield will be reduced. These effects are not seen until some months after the frost has occurred (Turner 2003). Low temperature and its duration causes irreversible chilling injury to banana plant (Table 5.2).

The distance between the petioles (leaf stalks) of alternate leaves is reduced during late winter to early spring making the plant look like a rosette. The bunches may fail to emerge properly. This is common in Dwarf Cavendish but not so common in cv. Williams. Choked bunches are prone to sunburn and produce fruits which are

Table 5.2 Time taken to produce irreversible chilling injury in banana (Source: Turner 2003)

Air temperature	Time taken to cause irreversible chilling injury
8°C	3 days
6°C	18 h
4°C	4 h
2°C	45 min
0°C	10 min
–2°C	2 min

difficult to pack. Choking can also be caused by high temperatures (above 30°C) and drought.

Fruits are uneven and often deformed if the bunches emerge during winter months (December to January) in subtropical regions. The temperature below 10°C leads to impedance of inflorescence and malformations of bunches**.** The fruit is tapered, being thin at the stalk end, and the flower end may have a conical, green protuberance. Fruit on the same hand is variable in length. Often the fruits are short and thick when mature (Turner 2003). The quality of the fruit is good and has a reputation for being the best tasting of all bananas. However, sometimes very few fruit develop to marketable size. November bunch has been observed in all subtropical countries where bananas are grown. It is associated with cool winter conditions occurring during the development of fruit on the bunch. The degree of deformity therefore changes according to the extent of cold of the previous winter. Low temperatures in the plantation and during transport to market can cause the chilling of fruit. The damage to fruit is a function of time and temperature. For example, a temperature of 2°C will cause damage only if it lasts for longer than 45 min. Chilling damage to fruit expressed as water soaked patches underneath the skin surface. Ripening becomes more difficult and the chilled skin turns black as the fruit ripens.

5.3.1.1 Impact of Temperature on Banana Flowering

In an established banana plantation, flowering will be almost uniform under humid tropics, with only a few variations, usually as a result of dry spells or a temporary drop in temperature (Simmonds 1966). But in subtropics, there are distinct climatic differences as summer and winter.

In Israel, under subtropical climate, established banana plantation flowering was recorded from March to November, but most of the flowering was concentrated in the months of June–September (~80%), which was influenced mostly by climatic factors. Flowering behaviour of banana was studied in the Jordan Valley of Israel by Israeli and Nameri (1988) by analysing all climactic factors and flowering for years 1963 to 1983. During these years, a slight but significant decrease in temperatures was recorded. A decrease of 0.6°C (between the mean of the years 1963–1971 and the years 1972–1983) was recorded and difference was significant. As a result, there was decline in percentage of flowering in July and August months of 1983 compared to earlier years (Israeli and Nameri 1988).

5.3.1.2 Impact of Climactic Factors on Seed Set in Banana

International Institute of Tropical Agriculture (IITA) has developed Black Sigatoka leaf spot-resistant plantain hybrids. One of the reasons for success of this programme was due to relatively high seed set rate, embryo success rate in IITA's breeding station at Onne, southeastern region of Nigeria. For example, *ca* 200 seeds were extracted from a bunch of the plantain cultivar 'Bobby Tannap' when it was pollinated with 'Calcutta 4' a wild diploid seeded banana (*Musa acuminata* subspp. *Burmannicoides*).

The seed set per bunch has been found to vary greatly among seed-fertile plantain cultivars with an average from <1 seed to 20 seeds per bunch. Furthermore, a large fluctuation in seed set was recorded within the same cultivar, e.g. in 'Bobby Tannap' seed set ranged from 0 to 219. This pattern of seed set was affected by climactic factors than any other factors. Ortiz and Vuylsteke (1995) studies concluded that, more seed set recorded, when parents were crossed in a month recorded with low temperature, low solar radiation and high relative humidity. Besides, 2n gametes were produced in higher number when environment recorded high temperature, high solar radiation and low RH.

5.4 Prediction of Climate Change on Banana Production

The global circulation model projected that the temperature rise around 1–2°C in the subtropical regions of the country may have positive influence on the banana growth development. This will especially favours the banana in Maharashtra, Gujarat, Uttar Pradesh, Bihar, Jharkhand, West Bengal, Orissa and North Eastern regions. The banana cultivation area may extend in these regions and further augments the production. However, further research on simulation modelling may have to be done and the model has to be validated. The banana cultivation areas of central and northern parts of the country will favour the banana growth and development and yield may increase as compared to present level of production. There is a possibility that more areas can be brought under banana cultivation in the subtropical conditions due to climate change.

In India, the temperature starts to increase over the country from March onwards and reaches a peak in May and June. The number of days with mean maximum temperature exceeding 38°C is high in Deccan plateau and central parts of India during March to May. By May, many parts of India record a mean daily maximum temperature of above 40°C. On an individual day the temperature can be over 46–49°C. July and August are the active monsoon months; during that period, the mean temperature over various regions of the country remains around 28–29°C. The temperature fluctuation observed throughout the country may favour the banana growth in the traditional banana-growing regions and also there is scope to increase in new areas. There may be chances of reduction in the cultivable area in these regions which experience both water shortage and high temperature but this cannot be predicted immediately. However, there is every chance of decreasing the productivity of banana, if the duration of the higher temperature prolongs during summer months coinciding with flowering and bunch development. Whether the loss incurred due to high temperature can be compensated by the increased CO_2 concentrations is still elusive. The only respite is that the average temperatures are expected to increase more near the poles than at equator.

5.5 Impact of Elevated CO_2 on Plant Growth and Development

Navarro et al. (1994) observed that the photosynthetic efficiency of cv. Petitte Naine banana plants grown in vitro decreased as the ambient CO_2 concentration increased. There was no difference in the *Fy/Fm* ratio between plants grown in either high or low CO_2 environments, indicating that ambient CO_2 concentration did not affect the photochemical efficiency of photosystem. A few weeks after the banana plants were placed in the controlled environment glasshouse, leaf starch concentration was higher for plants grown in the lower compared to the higher CO_2 concentrations, which presumably resulted in a higher specific leaf weight for plants in the lower CO_2 concentrations. However, we observed that plant growth was considerably less in the low compared to the high CO_2 environment. Thus, the increased photosynthetic efficiency coupled with a smaller sink: source ratio for plants grown in the lower CO_2 concentration may have resulted in a build-up of starch in the leaves. Sink or storage capacity is directly related to the long-term response to high CO_2 concentrations and sinks: source ratios considerably higher for plants in the high CO_2 environment (Schaffer et al. 1996). In summary, increasing the CO_2 concentration increased photosynthetic rate and biomass accumulation of banana plants. Although, increasing the CO_2 concentration lowered the photosynthetic efficiency, it was not sufficient to offset increased assimilation resulting from higher CO_2 concentrations (Schaffer et al. 1996). Banana being C_3 plant may perform well under elevated atmospheric CO_2 conditions.

5.6 Rainfall and Banana Production

The country experiences a contrasting moisture and thermal regime longitudinally. While the north-west regions (70° E) experiences arid conditions, across the same latitude (26°N) in the east (95°E), per-humid conditions are experienced with one of the world highest rainfall regime in the Khasi hill regions of Meghalaya. Data for the last 100 years shows that close to 33% of the nationwide monsoon rainfall occurs in July. August gets around 29% of all the monsoon rain while June and September each receive 19%. But when the IMD's National Climate Centre closely analysed the rainfall distribution between 1901 and 2003, they found that the contribution of June and August to the annual rainfall exhibited 'significant increasing trends'. The contribution of the July rainfall, on the other hand, showed a marked decline. Marked change in regional rainfall pattern has also been noticed. The July rainfall has been reduced and the August rainfall increased in central and west peninsular region covering much of Karnataka and Maharashtra, the Konkan-Goa region and eastern Madhya Pradesh.

In India, generally, banana planting is done based on water availability, rainfall, suitable time for flowering and bunch development. The planting is done in south Kerala during September–October months and in north Kerala during December month. In other parts of South India, planting time is February and March in the hill slopes and April in the plains. In the coastal area of Maharashtra, planting is done in June, August and October. For West Bengal region, it is in June–July and September and October seasons. The irrigation practice in different region of the country is based on tradition of field experience and generally empirical in nature. For banana, the irrigation is done at intervals of 15–20 days during beginning of the monsoon season (June), while during the active monsoon period, no irrigation is needed. The plantations need irrigations once or twice in September and 10–12 days interval from October to February and at intervals of 4–7 days from March to May during summer, depending on the severity of heat. Occasionally, even during the monsoon season, supplementary irrigation may be required for crops during the break periods with prolonged dry spells in July and August when the evaporating surfaces receive excessive heat load due to advective conditions (Sastry 1979). A mature Dwarf Cavendish banana plant could consume 25 L of water on clear day, 18 L on a partly clear cloudy day and 9.5 L on an overcast day.

Banana can take easily 30% available water from the soil at field capacity. At 60% depletion of available water, wilting may occur resulting in closure of stomata and a reduction in photosynthesis. In the tropics, ET is observed as 1.2–1.4 times of class a pan evaporation factor for well-watered soil with complete canopy, whereas in subtropics, under drip irrigation system, the rate was about 0.9 pan evaporation in midsummer. In the semiarid Marathwada region of central India, Kadam et al. (1978) estimated the reference crop evapotranspiration of banana and recorded 2,538 mm for crop duration of 510 days. The banana plants need continuous sources of soil moisture for optimum growth. There may be over 40 m^3 of 'plant water' in a hectare of banana plants in a day (Aubert 1966) and transpiration loss is estimated at 30–60 m^3. Any water deficit would thus retard its growth and the effects may sometimes be evident only several months after the drought (Stover 1972).

It is very clear that for banana cultivation, water should be available round the year; therefore, wherever the climate ensures the availability of enough irrigation water round the year, the banana cultivation will be expanded and intensified. If there is a shift in rainfall pattern, there must be a change in cultivation system and adaptation.

5.6.1 Flooding on the Growth and Yield of Banana

Fairly good soil drainage is known to be an essential condition which favours growth of the banana crop. Water logging with over irrigation in Robusta plant reduces the bunch weight and other growth parameters (Holder and Gumbs 1983). Bananas subjected to flooding for more than 48 h are severely stunted in further development and after 72–96 h, there are no recovery of the mature shoots (Stover 1972) and often die. New suckers emerge from the rhizomes but these are of the water type, and slow growing. Flood injury is usually greater when strong sunlight and warm weather follow flooding. In heavy precipitation and flood prone and low lying areas which earmarked for banana cultivation, the land must be prepared with better slope and drainage system.

5.7 Climate Change on Weed and Pests

Weeds, insects and diseases are all sensitive to temperature and water, and some organisms are also receptive to atmospheric CO_2 concentrations. Altered temperature, rainfall pattern and humidity have an impact on development and distribution of banana insect pests and diseases. Increase in temperature and CO_2 will lead to an increase in population of pests and severity of diseases in presence of host plant. The increase in insect population leads to demand for more use of pesticide, which unknowingly causes lots of harm to ecosystem as well as to human health. Incidence of pest and diseases would be most severe towards equatorial regions due to higher impact of climate change. Pest and disease of plain ecosystem may gradually shift to hills and mountains as the temperature rises. The pests like banana weevils, aphids (vector of viral disease) may have more population in the changed environment. The leaf spot disease may spread and become severe towards northern belt of India as favourable temperature will be available there. At Jalgaon, the leaf spot diseases were not seen earlier but off late leaf spot and cucumber mosaic virus diseases have started appearing. This development may be due to climate change effects.

5.8 Adaptation to Climate Change

- Raising awareness within farming communities on ways to adapt to climate change and for providing better information on challenges and solutions.
- Development of cost-effective technologies.
- Change varieties and alter the planting and harvest dates: an effective, low-cost option. The major risk is that this will put farmers into a different market window with lower prices.
- Water conservation measures by farmers need to be promoted to increase resilience to climate change and these activities should become more widespread. Significant efforts are necessary in regions where agriculture uses major portion of the total water resource. Water-saving measures include rainwater harvesting, crop rotations that make best use of available water, the adjustment of sowing dates according to temperature and rainfall patterns, the use of crop varieties better suited to new weather conditions (e.g. crop varieties with shorter cycles, more resilient to water stress), the adoption of water conservation practices that favour infiltration and the reuse of waters should be practised wooded areas on arable land that reduce water run-off and act as windbreaks. Beyond the farm level, measures such as modernising the irrigation infrastructure can be applied.

5.8.1 Challenges Ahead

Although warmer temperatures in the northern part of India, longer growing seasons and elevated CO_2 concentrations are generally expected to benefit agriculture, factors such as reduced soil moisture, increased frequency of extreme climate events, soil degradation and pests have the potential to counteract these benefits. In Indian subcontinent, some regions could experience net gains, while others may see net losses.

Regional variations will result from several factors, including the nature of climate change, the characteristics of the farming system/organisation and the response of different groups.

Appropriate adaptations have the potential to greatly reduce the overall vulnerability of agriculture to climate change. These adaptations will require the participation of several groups, including individual producers, government organisations, the agri-food industry and research institutions. Historically, the agricultural sector has proven itself to be highly adaptive to environmental and social changes, with a strong capacity to adapt in a responsive manner. However, to most effectively reduce vulnerability, anticipatory adaptation is necessary. For example, efforts to increase adaptive capacity through diversification and the development of new technologies represent valuable types of proactive adaptation. Anticipatory adaptation is also important with respect to major capital investments by producers and the agri-food industry.

5.9 Conclusion

The research indicated that climate change will have a negative effect on Indian agriculture, though varying by season and region. Banana production and area will be increased as subtropical northern part of India will favour banana production and present banana-growing area will be sustained with present technologies to mitigate climate extremes. But farmers' adaptation to climate change through changes in farming practices, cropping patterns and use of new technologies will help to ease the impact. Simulation model studies are required to predict and validate the impact of climactic factors on banana production in Indian subcontinent region.

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6

Harmonious Phenological Data: A Basic Need for Understanding the Impact of Climate Change on Mango

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Abstract

Uniformly collated phenological data set is the most important requirement for developing climate change impact models for mango. Consistently collected phenological records directly indicate the effect of change in climatic parameters by depicting shifts in phenological events. Recording of consistent data pertaining to phenophases as a function of time serves as critical input for working out integrated interaction of interannual variability, spatial differences and climate variability impacts. In general, uniform qualitative data recording is difficult in mango due to variations in plant growth and development under diverse climatic fluxes occurring in subtropical to tropical regions. Major observed effects of climate change on mango include early or delayed flowering, multiple reproductive flushes, variations in fruit maturity, abnormal fruit set and transformation of reproductive buds into vegetative ones. These critical phenophase-dependent events require supporting quantitative data

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representing behaviour of sufficient number of shoots within a tree for objective analysis of factors influencing them. For monitoring the phenophase dynamics, use of extended BBCH (Biologische Bundesanstalt, Bundessortenamt und Chemische Industrie) scale developed for mango helps in monitoring the phenology by employing uniform methodology over same or different locations with the description of each phenophase in mango as distinctly classified by adopting numerical code. A manual to elucidate the methodology for general users has been developed with the help of pictorial representation of phenophases along with corresponding scores, analysis, depiction of results and interpretation for uniform data recording, and this can be downloaded from http://offseasonmango.cishlko.org/phenology.pdf.

6.1 Introduction

Climate is one of the most important factors controlling growth, yield and success of mango orcharding in a variety of ways. It is evident that natural systems are changing due to changing global climate in the timings of phenological events. Among all the studies and evidence on changing natural ecosystems considered by the IPCC third assessment report (IPCC TAR 2001) on climate impacts, major findings come also from changes in phenological events. Growth and flowering behaviour around the world has indicated that phenological events have changed in mango; for example, early or delayed flowering, multiple reproductive flushes, variations in fruit maturity, abnormal fruit set and transformation of reproductive buds into vegetative one are becoming common.

Phenology is generally described as observation of the life-cycle phases of plants and their relationship with the environment, especially climatic factors. It involves investigation of the plant responses to seasonal and climatic changes in the habitat. Seasonal changes include variations in temperature, rainfall, precipitation, humidity, wind, duration of sunlight, soil temperature, atmospheric circulation, frost and other life-driving factors. Leaf flush, leaf unfolding, flowering, bud burst and fruit ripening are all examples of phenological events or phenophases. Therefore, phenophases are regulated mainly by climatic factors and to a much lesser extent by inner factors of the organism (e.g. genetic regulation, plant hormones). The basic pattern and its plasticity are genetically determined and then modified by the environment. However, temperature is considered the driving factor determining phenological phases because the commencement of each development period for plant requires certain critical and accumulated temperatures.

6.2 Why Phenology Is Important in Climate Change Studies?

It is now well conceptualized that mango phenology has an important connection to climatic components. Numerous examples are evident, early and delayed flowering, fruit ripening, vegetative flushing and multiple flowering, showing that global warming is significantly changing the phenophase seasonality of mango. Due to its sensitive response to climate, phenology responses of mango can be used as an indicator for environmental monitoring, particularly in detecting climate change. It is possible to model the relationship between phenophases and climatic elements only with the availability of long-term phenological data. Study of changes in the timing of plant phenophases in response to climate warming is important for two reasons. First, it demonstrates that climate change is already happening even in response to the current modest increase in temperature, and second, it indicates the extent of change in natural ecosystems that we can expect in the future. Future response of mango to a changed climate can only be predicted by exploring how the crop responded to climate in the past. The use of phenology as a sensitive bioindicator presupposes quantitative analysis of changes in phenological time series and a known relationship with temperature or a comparable change in corresponding temperature series over time.

6.2.1 A Brief History of Phenology

Phenology is an ancient scientific discipline, the history of which dates back to the time of the hunter-gatherers. Monitoring seasonal natural events such as the date of spring blooming of a particular plant species is a centuries-old practice. Keeping records of plant phenology was both a hobby and a tradition for natural historians in many countries. Phenological calendars were used by the ancient Chinese and the Romans to guide agricultural operations, as well in the UK and Japan. Some Chinese phenological series stretch back to the sixteenth century or earlier. In Britain, the long history of recording phenological observation goes back at least 250 years, with the oldest records dated 1703. The systematic collection of phenological records in Britain started in 1736 when Robert Marsham, near Norwich, began to collect 'indicators of spring', particularly flowering, leafing and bird migration dates. Five generations of the Marsham family recorded phenological observations at their estate from 1736 through to 1958, forming the longest phenological record by one family in the world. The Marsham phenological records were related to long-term climate records. Carolus Linnaeus and Robert Marsham now share the honour of being considered the 'fathers' of modern plant phenology.

After the 1990s phenological research gained momentum in the context of research into global change, and a large number of research findings were published on the impacts of climate change on phenological events. As a result some nature-based organizations shifted their focus and deployed their efforts to phenological research. Due to increased research interest in global environmental change and interannual climatic variability, long-term phenological data are becoming essential inputs to climate models. Phenological modelling plays a prominent role in regional ecosystem simulation models and atmosphere general circulation models. Phenological records and models are used in agricultural production, integrated pest- and invasive-species management, drought monitoring, biodiversity, forestry, wildfire risk assessment and treatment of pollen allergies. Therefore, phenology has recently developed rapidly and globally as an environmental science discipline.

6.3 Uniform Phenological Monitoring Methodology for Mango

Uniformly collated phenological data set is the most important requirement for developing climate change impact models for mango. Consistently collected phenological records directly indicate the effect of change in climatic parameters by depicting shifts in phenological events. Recording of consistent data pertaining to phenophases as a function of time serves as critical input for working out integrated interaction of interannual variability, spatial differences and climate variability impacts. In general, uniform qualitative data recording is difficult in mango due to variations in plant growth and development under diverse climatic fluxes occurring in subtropical to tropical regions.

To study the phenological behaviour of the mango in an easy and quick way with more precision, understanding of the methodology for recording and analysis of the data can be of prime importance. Although, some manuals are available to study the phenological behaviour of the forest plants such informative literature customized for mango is lacking. Therefore, for better understanding of the principle and application, need for a manual was felt which can provide consistent methodology to collect high quality, harmonized and comparable phenological data on mango.

Few scales were developed to study the mango phenology are available [Fleckinger's scale (1948), Aubert and Lossois's scale (1972)], but the most simple and significant scale for mango is BBCH (BBCH = Biologische Bundesanstalt, Bundessortenamt und Chemische Industrie) scale modified by Hernandez et al. (2011) and Rajan et al. (2011) for mango. A study was carried out to signify the application and validity of the data collected by employing modified BBCH scale at CISH, Lucknow, and the methodology developed for interpretation and presentation of data is described in brief in the manual (Rajan et al. 2012).

6.3.1 Description of the Modified BBCH Scale

The modified scale covers the entire developmental cycle of mango and is subdivided into eight clearly recognizable and distinguishable principal growth stages out of 10 of general BBCH scale. Each principal growth stage is classified into secondary stages which describe points in time or shorter developmental intervals in the major growth stage. This scale starts with bud development (stage 0) and terminated at maturity of fruit (stage 8). In addition to this, the most important phase of plant growth and development, i.e. senescence (stage 9), is described in the modified BBCH scale for mango. The dried/dead shoots, barren panicle and dried/dropped-off panicle are covered under this principal growth stage. The secondary stages are numbered 0–9 that describes related percentile stages of growth. Several mesostages (1 to n) are used to describe the different vegetative and floral flushes during season for coding bud, leaf and shoot development. Therefore, a list of phenological stages of mango can be made in ascending order by sorting codes into numerical order (Table 6.1). As the individual phases of phenological phenomena occur, assessments need should be repeated until the phase is completed. In principle, all phenophases are of interest for phenological monitoring. However, from practical point of view (e.g. financial input, ease and reliability of the monitoring, wide comparability, compatibility with research objectives), it is necessary to concentrate on a limited set of phenophases. The important stages for mango may be considered as 010, 011, 019, 110, 119, 319, 510, 511, 513, 610, 615, 619, 701, 709 and 801. This may be further modified according to one's need to economize the recording of data without loss of available required information.

6.3.2 Criteria for Selection of the Trees

The trees to be assessed should be selected from those orchards which have grown under good management practices. Random sampling should be done for selection of the trees for the assessment. The number of trees to be selected for phenological monitoring depends on the conditions of trees and availability of human resources. All shoots should be numbered and tagged. If there is an insufficient number of shoots, additional trees should be selected from the orchards as good visibility of the selected shoot is necessary. Trees being used for leaf/bud/shoot sampling should not be included. The same part of the tree should be considered for subsequent phenological observations throughout the year as well as for subsequent years.

6.3.3 Frequency of Observations

The frequency of observations depends on the season and objective of the research. A frequency of at least once a fortnight during the growing period is recommended. The minimum required frequency is once a week during the critical phases, but daily observation is the optimum for studies specific to certain phenophases requiring short period for completion. There is no requirement of any kind of equipment and observations should be recorded manually by technically sound persons. As accuracy of the phenological

Table 6.1 Modified BBCH scale for mango (Rajan et al. 2011)

Principal Growth Stage	Code	Description
0 Bud development		
First vegetative flush	010	Dormancy: leaf buds are closed and covered with green or brownish scales
	011	Beginning of leaf bud swelling: bud scales begin to separate
	013	End of leaf bud swelling: scales completely separated, light green buds emerged
	017	Beginning of bud break: light green to dark coppery tan leaf tips just visible
	019	Bud break: light green to dark coppery tan leaf tips visible 5 to 10 mm above bud scales
Second vegetative flush	020	Dormancy: leaf buds are closed and covered with green or brownish scales
	021	Beginning of leaf bud swelling: bud scales begin to separate
	023	End of leaf bud swelling: scales completely separated, light green buds emerged
	027	Beginning of bud break: light green to dark coppery tan leaf tips just visible
	029	Bud break: light green to dark coppery tan leaf tips visible 5 to 10 mm above bud scales
1 Leaf development		
First vegetative flush	110	Leaf tips more than 10 mm above bud scales
	111	First leaf unfolded
	115	More leaves unfolded: petioles visible
	119	All leaves completely unfolded and expanded
Second vegetative flush	120	Leaf tips more than 10 mm above bud scales
	121	First leaf unfolded
	125	More leaves unfolded: petioles visible
	129	All leaves completely unfolded and expanded
3 Shoot development		
First vegetative flush	311	Beginning of shoot growth: axis of developing shoots visible, about 10 % of final length
	312	Shoots about 20 % of final length
	315	Shoots about 50 % of final length
	319	Shoots about 90 % of final length
Second vegetative flush	321	Beginning of shoot growth: axis of developing shoots visible, about 10 % of final length
	322	Shoots about 20 % of final length
	325	Shoots about 50 % of final length
	329	Shoots about 90 % of final length
5 Inflorescence emergence		
Principal flowering	510	Buds closed and covered with green or brownish scales
	511	Beginning of bud swelling, scales begin to separate
	513	Bud burst: first floral primordial just visible, panicle development begins
	515	Flowers are visibly separated, secondary axes begin to elongate
	517	Secondary axes elongated, flower buds are swollen and first light green to crimson petal tips visible in some flowers. In mixed panicles, leaves have reached final length
	519	End of panicle development: secondary axis fully developed, many flowers with green to crimson petal tips visible and some opened, leaves fully developed in case of mixed panicles

(continued)

Table 6.1 (continued)

Principal Growth Stage	Code	Description
Secondary flowering	520	Axillary flower buds of the apical dome are closed and covered with green or brownish scales
	521	Beginning of bud swelling, scales begin to separate
	523	Bud burst: first floral primordial just visible, panicle development begins
	525	Flowers are visibly separated, secondary axes begin to elongate
	527	Secondary axes elongated, flower buds are swollen and first light green to crimson petal tips visible in some flowers. In mixed panicles, leaves have reached final length
	529	End of panicle development: secondary axes fully developed, many flowers with green to crimson petal tips visible and some opened, leaves fully developed in case of mixed panicles
6 Flowering		
Principal flowering	610	First flowers open
	611	Beginning of flowering: 10 % of panicle flowers open
	613	Early flowering: 30 % of panicle flowers open
	615	Full flowering: more than 50 % of panicle flowers open
	617	Flower fading, majority of petals fallen or dry
	619	End of flowering, all petals fallen or dry, fruit set
Secondary flowering	620	First flowers open
	621	Beginning of flowering: 10 % of panicle flowers open
	623	Early flowering: 30 % of panicle flowers open
	625	Full flowering: more than 50 % of panicle flowers open
	627	Flower fading, majority of petals fallen or dry
	629	End of flowering, all petals fallen or dry, fruit set
7 Fruit Development		
Main season fruit development	711	Fruits at 10 % final size, styles still visible, beginning of physiological fruit drop
	713	Fruits at 30 % of final size, end of physiological fruit drop
	715	Fruits at 50 % of final size
	719	Fruit at standard cultivar size, shoulders fully developed, flesh creamy green in colour
Second season fruit development	721	Fruits at 10 % final size, styles still visible. Beginning of physiological fruit drop
	723	Fruits at 30 % of final size, end of physiological fruit drop
	725	Fruits at 50 % of final size
	729	Fruit at standard cultivar size, shoulders fully developed, flesh creamy green in colour
8 Maturity of fruit		
Main season fruit development	810	Physiological maturity: fruit fully developed, flesh creamy green in colour
	811	Beginning of skin colour change
	819	Fruit colour fully developed, fruit ripe for consumption with correct firmness and typical taste
Second season fruit development	820	Physiological maturity: fruit fully developed, flesh creamy green in colour
	821	Beginning of skin colour change
	829	Fruit colour fully developed, fruit ripe for consumption with correct firmness and typical taste
9 Senescence		
Principal vegetative flush/ flowering	911	Barren panicle
	916	Dried shoot, dried or dropped panicle
Second vegetative flush/flowering	921	Secondary flowering: barren panicle
	926	Dried shoot, dried or dropped panicle

data depends on the degree of precision intended by the user, field staff should be trained. A photo guide with almost all phenological stages for mango tree made available for this purpose (Fig. 6.1).

6.4 Data Analysis and Interpretation

The present investigation is based on the work carried out at five diverse eco-geographical locations of Lucknow (subtropics, hot subhumid (dry) ecoregion), Bangalore (Central Karnataka Plateau, hot moist semiarid), Kanyakumari (hot subhumid to semiarid ecoregion), Medak (hot semiarid ecoregion) and Dapoli (West Coast Ghat region) by collecting phenological data and analysing them with the help of BBCH scale developed for mango. The observations recorded on the basis of the BBCH scale are uniform and describe all the growth and developmental stages of mango but generates a large data set and unmanageable for manual interpretation. Thus, the phenophases of selected shoots are summarized on the basis of per cent shoots under particular stage at a specific time. The value indicated the proportion of phenophases and total number of selected shoots (Table 6.2). This interpretation of the data confers the condition of the whole tree.

Phenological data collected on mango trees with the help of BBCH scale generated a large data set, and manual interpretation was difficult. The phenophases of selected shoots were summarized on the basis of per cent shoot under particular stage at a specific time out of total number of selected shoots. BBCH scale-based data is depicted in the form of line graph for identifying phenological stages with highest score at each standard week (Fig. 6.2a). This indicates changes occurring among different phenophases for the identified shoots during particular period and can identify the occurrence of the most frequent stage by viewing the graphical representation. The occurrence of the phenophases was correlated with the prevailing temperature and rainfall (Fig. 6.2b). Brief description of the analysed data represented in the Fig. 6.2a has showed the following transition pattern of phenophases in mango:

1. The stage 010 was recorded with highest percentage in standard week 33 and increased up to 73.3% in standard week 36 indicating rapid growth of shoots. Thereafter, per cent of shoots at stage 010 became constant from standard week 46–51 indicating cessation of growth during the period. From standard week 52, the vegetative growth started and frequency of stage 010 increased. The increment in the percentage of shoots having stage 010 indicated the initiation of vegetative growth.
2. During standard week 33, stage 916 recorded 16.7% as compared to other phenological growth stages. Up to standard week 35, the rise in percentage of shoots in stage 916 indicated the transition of stages 911–916. The constant frequency indicated no further growth in shoots at stage 916 or drying of the shoots.
3. The high degree of variation in percentage of shoots related to principal growth stages, viz. vegetative bud, leaf and shoot development, was observed due to simultaneous transition of the stages during standard week 33–42 and 4–24. The longer and shorter duration between stages 010 and 319 indicated the slow growth and rapid growth of shoots from standard week 33–42, respectively.
4. The stages indicating growth in inflorescence were observed from standard week 3 and continued till standard week 12. The stages 511 (initiation of inflorescence) and 517 (light green to crimson petal tips visible in some flowers) were recorded from standard week 3–11 and 10–12, respectively.
5. The stage 619 (fruit set) was observed between standard week 12 and 16.
6. The stages for fruit development (701–709) were recorded during standard weeks 16–24.
7. The stage 911 in standard weeks 12–16 indicated the existence of barren panicles due to drying or dropping of flowers from the panicles, while in later standard weeks such as from week 17 and onwards, the stage 911 represented the barren panicle after fruit drop.

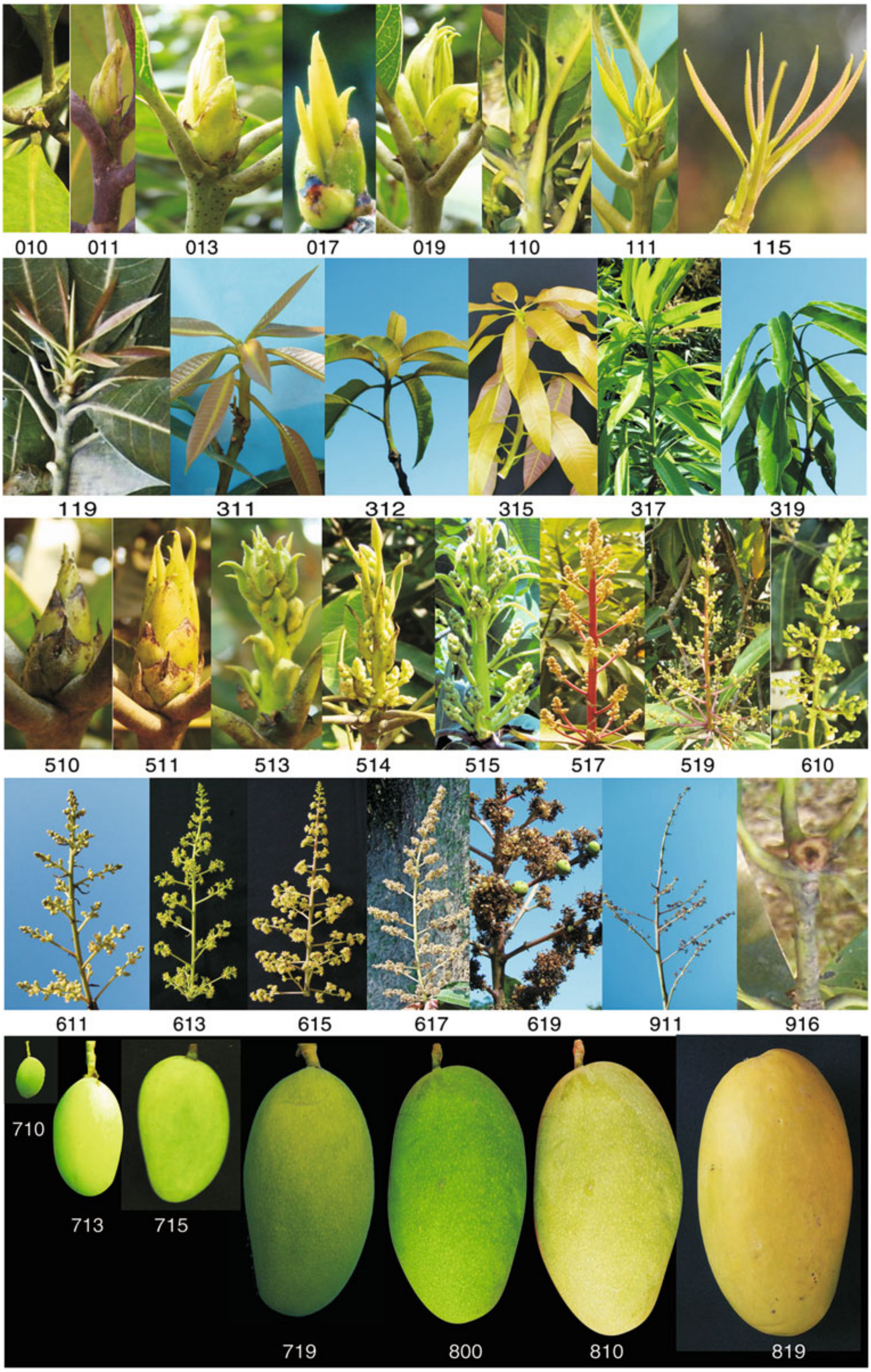

Fig. 6.1 Phenological stages of mango

Table 6.2 Percentage of shoots (using BBCH scale) under different phenophases during August 2010 to June 2011

Month	Std. wks	10	11	13	17	19	110	111	115	119	311	315	319	510	511	513	515	517	519	617	619	703	705	709	911	916
Aug	33	42	5		10	3.3							15												8.3	17
	34	1.7			3.3		3.3	32	1.7	32			1.7												3.3	22
	35				1.7					1.7	6.7		65													25
	36	73	1.7				1.7						3.4													20
Sep	37	1.7	1.7		3.3	45	17	10					3.4													18
	38	1.7					1.7			22	52		3.4													20
	39	68										1.7	8.4													22
	40		1.7		6.7	8.3		1.7		57			3.4													22
Oct	41							3.3		13			62													22
	42	63	3.3		1.7						6.7		12													13
	43	3.3	13		67	3.3																				13
	44							5		78																13
Nov	45									20	1.7		65													13
	46	55	6.7								5		22													12
	47	55	6.7								5		22													12
	48	55	6.7								5		22													12
Dec	49	55	6.7								5		22													12
	50	55	6.7								5		22													12
	51	55	6.7		1.7						5		22													10
	52	58						1.7			3.3		22													15
Jan	1	58									5		22													15
	2	58									3.3		23													15
	3	58	1.7								1.7	1.7	20	1.7	1.7											13
	4	57			1.7					3.3			25	5	1.7											6.7
Feb	5	47	13							1.7	3.3		20	6.7	1.7											6.7
	6	23	30	10	1.7						3.3		13	3.3	6.7	1.7										6.7
	7	17	17	30	3.3	3.3							3.3	12	5	5										5
	8	17	3.3	20	10	5		1.7	1.7				3.3	12	12	8.3										6.7
Mar	9	15	3.3	18	3.3		1.7	5					1.7	5	18	20	3.3									1.7
	10	12		1.7	1.7	10	1.7			12			1.7		20	6.7		32								1.7

(continued)

Table 6.2 (continued)

Month	Std. wks	10	11	13	17	19	110	111	115	119	311	315	319	510	511	513	515	517	519	617	619	703	705	709	911	916
	11	10	1.7	3.3				1.7		27			1.7		1.7	3.3	1.7	45	3.3							
	12	5		3.3	1.7					3.3	12		17					3.3	1.7	25	23				3.3	1.7
April	13	13		1.7	1.7		1.7				3.3	1.7	18						1.7	6.7	38				6.7	5
	14	28		3.3	3.3	6.7				1.7	1.7	1.7	3.4								32				13	3.3
	15	18	6.7	3.3	1.7	3.3		1.7	1.7	1.7	5		6.7								30				12	6.7
	16	10		1.7	3.3	8.3		3.3	1.7	8.3	5		8.3							1.7	27				12	10
May	17	13		3.3				1.7		12	15		8.4							1.7			6.7	1.7	22	8.3
	18	25								1.7	13	1.7	17								1.7	3.3	3.3	3.3	22	8.3
	19	40	1.7								1.7		17									1.7	5	3.3	18	12
	20	53	1.7								5		5										5	5	10	15
June	21	65									3.3		3.3										1.7	8.3	6.7	12
	22	58		6.7	1.7	1.7					3.3													10	6.7	12
	23	40	13	6.7	1.7	1.7					3.3	1.7												10	6.7	15
	24	37			3.3	1.7		1.7		18	3.3		3.3											8.3	6.7	17

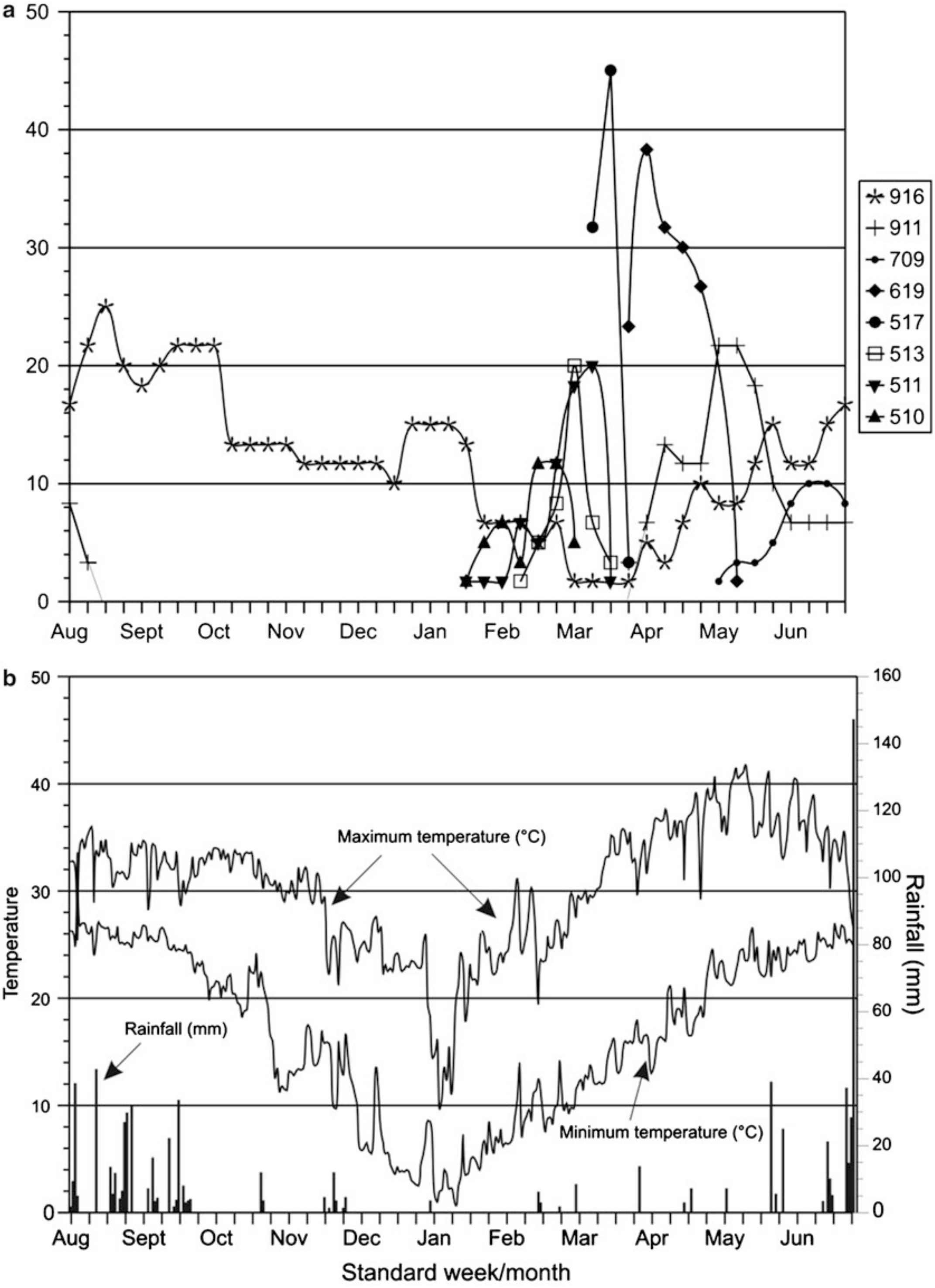

Fig. 6.2 Percentage of shoots under different phenophases (**a**) and weekly meteorological data (**b**) during August 2010 to June 2011

Table 6.3 Timing of important phenophases under different agro-ecologies

Phenophases	CISH, Lucknow	IIHR, Bangalore	DBSKKV, Ratnagiri	APHU, Medak	FRS, Kanyakumari
510	2nd week of Jan	1st week of Jan	3rd week of Oct	1st week of Jan	2nd fortnight of Dec
513	4th week of Jan	3rd week of Jan	1st week of December	3rd week of Jan	2nd fortnight of Dec
610	2nd week of March	2nd week of Feb	2nd week of December	4th week of Feb	4th week of Jan
615	3rd week of March	3rd week of Feb	1st week of Jan	1st week March	1st fortnight of Feb
619	4th week of March	1st week of March	3rd week of Jan	3rd week of March	2nd fortnight of Feb
709	1st week of July	2nd week of April	4th week of March	4th week of May	1st week of May
801	2nd week of July	3rd week of April	1st week of April	3rd week of June	2nd week of May

On the basis of analysed data, the timing of different phenophases was recorded for all the ecological locations which are summarized in the following Table 6.3.

6.5 Need for Online Mango Phenology Network

The UK Phenology Network (UKPN) coordinated by the Woodland Trust and the Centre for Ecology and Hydrology was started in 1998 with the aim of creating a large-scale network of phenology recorders and to search for and preserve historical data. Currently there are more than 20,000 registered volunteer recorders throughout the UK who have already recorded over one million observations from both plants and animals.

The experiences of the UK Phenology Network revealed that it is possible to communicate and disseminate climate change issues to the general public effectively and that phenology has shown itself capable of reconnecting people with nature. Thus, there is a need for developing National Online Mango Phenology Network to bring together scientists, government agencies, non-profit groups, educators and students to monitor the impacts of climate change on mango in India. The network will also harness the power of people and the Internet to collect and share information on phenology by providing researchers with far more data than they could collect alone for developing strategies to reduce the vulnerabilities of mango production to weather dynamics.

6.6 Implications for Impacts of Climate Change on Phenology of Mango

There may be very little study on the impacts of climate change on the phenology of mango, and studies carried out in these areas are either fragmentary or inconclusive. It is now evident that delaying or advancing of flowering is happening and extreme weather events and climate variability are magnifying it. Delay or advance of the arrival of summer, rainy and winter season may disrupt the natural rhythm or synchrony of the ecosystems. It is interesting that some of the newspapers also report about earlier flowering of mango in several parts of Asia. The long-term implications of changes in the phenology of mango may be profound for different ecosystem in mango growing areas of the world. Long-term data are generally required to find out fingerprint of climate change. Though it is already late, there is need to start immediately to collect phenological data every year from different agro-ecological zones which will be an important source for interpreting climate signals from those data. On the other hand, availability of climatic data, e.g. air temperature, rainfall, sea surface temperature and soil temperature, will form a basis for understanding of differential flowering behaviour of mango under different ecologies. For this purpose, both climatic data and phenological data are required to detect climate change trends.

Thus, there is a need of National Online Mango Phenology Network to collect the phenological data under diverse agro-ecological conditions in India to bring together scientists, government agencies, non-profit groups, educators and students to monitor the impacts of climate change on mango. The network will also harness the power of people and the Internet to collect and share information on phenology by providing researchers with far more data than they could collect alone for developing strategies to reduce the vulnerabilities of mango production to weather dynamics.

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7 Effect of Climate Change on Grape and Its Value-Added Products

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Abstract

In India, majority of the grape vineyards are located in semiarid climate. Climate change may aggravate the already serious problems of irrigation water availability and salinity. The elevated CO_2 levels may increase productivity in arid and semiarid regions, but the drought stress caused by higher evaporative demand may override beneficial effects of increased CO_2 in the atmosphere unless irrigation is increased to compensate the evaporative demand. Higher temperature may advance the ripening of berries and alter the berry composition in both table and wine grapes, thereby affecting the quality of the produce. Developing heat-tolerant grape varieties and salt- and drought-tolerant rootstocks, though essential, requires long period. Until new varieties/technologies are developed to improve water use efficiency and cope up with salinity, the emphasis needs to be given on propagation of existing crop production techniques that can mitigate the impact of climate change. There is also likelihood of change in the incidence and pattern of insect pests like mealy bug, thrips and mites. Similarly the disease incidence pattern is also likely to be affected with the change in climate. This is evidenced by decrease in productivity during the recent years from more than 25 t/ha to 8.3 t/ha during the year 2009–2010 and11.7 t/ha during 2010–2011 due to unseasonal rains which lead to serious downy mildew incidence. Changes in cropping season to adjust to changed climate will bring market competition-related issues particularly for Indian table grape industry in domestic as well as global markets.

7.1 Introduction

Grape is one of the most important horticultural crops, growing in 0.11 million ha area with a production of 1.235 million t (Anonymous 2012). Majority of the grape-growing areas are in the semiarid tropics with problems of drought and salinity being important abiotic stresses. The

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productivity which was once more than 25 t/ha in India declined to 8.3 t/ha during 2009–2010 and 11.7 t/ha during 2010–2011 (Anonymous 2011, 2012) due to serious downy mildew disease developed by the unseasonal rains during the critical growth period. According to FAO (2003), production systems in marginal areas with respect to water face increased climatic vulnerability and risk under climate change, due to factors that include, for instance, degradation of land resources through soil erosion, overextraction of groundwater and associated salinization and overgrazing of dry land. More than 90% of simulations predict increased droughts in the subtropics by the end of the twenty-first century (Bates et al. 2008), while increased extremes in precipitation are projected in the major agricultural production areas of southern and eastern Asia, eastern Australia and northern Europe.

Worldwide, grape-growing regions are often classified into so-called Winkler regions according to heat summation measured in cumulative growing degree days (GDD), a scheme originally proposed by Amerine and Winkler (1944). This method sums up the mean daily temperatures above a threshold typically set at 10°C over a 7-month "standard" growing season (April–October in the northern hemisphere and October–April in the southern hemisphere). Each 1°C increment in mean temperature adds 214 GDD to the standard growing season. Therefore, if one assumes an average increase from the present of 1.5°C by 2020, cumulative heat units would increase by 321 GDD. A 2.5°C increase by 2050 would add 535 GDD to the current heat units. This simple estimate shows that the projected rise in temperature associated with global climate change (IPCC 2007) will likely shift several of the world's growing regions into the next higher Winkler region by 2020 and that this shift will affect most regions by 2050. In addition to the predicted temperature rise, the atmospheric CO_2 concentration which is currently ~ 380 ppm is projected to reach up to 600 ppm by the end of the twenty-first century, which is expected to accelerate the warming trend (IPCC 2007).

Although hot extremes and heat waves are set to become more frequent over the course of this century (IPCC 2007), the most imminent challenges facing the wine, table grape and raisin industries in arid and semiarid regions are probably not heat waves per se but increasing drought and salinity because of higher evaporation coupled with declining water availability (Schultz 2000; Stevens and Walker 2002). The precipitation patterns are changing, perhaps raining at undesirable times, and encouraging excessive vegetation early in the season or fostering fungi and mildew. Warming climates are sure to encourage new pests and diseases, notably insects following their habitat change. They may also affect the natural parasites and predators increasing pest attack due to change in the natural ecosystem. There may be changes in pathogen populations and introduction of new pathogens to new areas (Garrett et al. 2006). Further, seasonal changes in climatic conditions, too, are impacting grape productivity either in terms of reduced fruitfulness due to high temperature, increased disease and pest problems due to unseasonal rainfalls and/or salinity due to reduced rainfall. In fact, the seasonal changes can also influence the formation and ratio (at favourable levels) of sugar and pro-phenols in grapes, thereby affecting the quality of produce.

7.2 Effect of Elevated CO_2 Levels on Water Use Efficiency and Quality of Grapes

Studies carried out earlier on grapevine response to elevated carbon dioxide revealed that doubling the carbon dioxide in the atmosphere results in strong stimulation of yield without having any negative or positive repercussion on grapes at maturity stage (Bindi et al. 1996, 2001; Bindi and Fibbi 2000). Acid and sugar contents were also stimulated by rising CO_2 levels up to a maximum increase in the middle of the ripening season (8–14%); however, as the grapes reached the maturity stage, the CO_2 effect on both quality parameters almost completely disappeared (Bindi et al. 2001). Jose et al. (2006), using elevated CO_2 levels of 365 ± 10 ppm and 500 ppm ± 16 ppm on *Vitis vinifera* L. cv Touriga Franca, found that the net carbon dioxide assimilation rate increased significantly and stomatal conductance reduced in elevated CO_2 leading to improvements in intrinsic water use efficiency, reduction in stomatal density and increase in leaf thickness. However, titratable acidity, tartaric acid, malic acid and wine compounds were not significantly affected. Goncalves et al. (2009) reported from experiment on grapevines grown either in open-top chambers with ambient (365 ± 10 ppm) or elevated (500 ± 16 ppm) CO_2 or in an outside plot, that, in general, the increase of CO_2 did not affect berry characteristics, especially the total anthocyanin and tannin concentrations. However, the total anthocyanin and polyphenol concentrations of the red wine were inhibited under elevated CO_2. They further predicted that rise in CO_2 did not produce negative effects on the quality of grapes and red wine; although some of the compounds were slightly affected, the red wine quality remained almost unaffected.

According to Schultz (2011), one of the biggest "unknowns" and thus challenges in the discussion on sustainability and climate change is related to the lack of knowledge about how plants, microorganisms and pathogens will respond to a rise in CO_2 concentration, temperature and a possible lack of water simultaneously under field conditions. For this challenge to be met, the primary limitation is the establishment of sufficiently large infrastructures to simulate future climate developments such as increased CO_2 concentration and temperature under field conditions. Recent results from models including the physiological impact of CO_2 on plants (more biomass, reduced stomatal conductance) suggest that rising CO_2 will increase the temperature-driven water evaporation from the oceans resulting in an increased absolute water vapour content of the air. However, the decrease in evapotranspiration over land (due to a decrease in stomatal conductance) would still lead to an overall decrease in relative humidity and to an increased evaporative demand according to current knowledge (Boucher et al. 2009). Plant surfaces should then heat up more due to stomatal closure adding to the complexity of expected responses difficult to trace and simulate in conventional experiments (Schultz 2011). Earlier studies by Bindi et al. (2001) showed an increase in the fruit sugar concentration and a reduction in acidity levels under elevated CO_2, but the response of other components contributing to flavour and aroma of grapes was heterogeneous and indicated a significant "chamber effect", with plants grown outside responding differently than plants in open-top chambers with or without elevated CO_2 (Gonçalves et al. 2009).

From the above findings, it appears that grapes in arid regions may, therefore, benefit from increased CO_2 and partly overcome some of the adverse conditions created by drought as reported by Schultz (2000). Furthermore, expected rise in CO_2 concentrations may strongly stimulate grapevine production without causing negative repercussions on quality of grapes and wine. In the absence of environmental stresses, grapevines would perform well under increased atmospheric CO_2. But on the whole-plant level, long-term elevated CO_2 exposure probably may have very different effects. The initial increase in photosynthesis may be partly or completely downregulated if sinks for the photosynthates are not sufficient over a period of time (days, weeks or months of growth) in elevated CO_2, the acclimation response may be substantial enough that the photosynthetic rates of plants grown and measured in elevated CO_2 may even become equal to those grown at current ambient concentrations (Bazzaz 1998). It is difficult to predict the combined action of several changing environmental factors. Faster development of larger leaf areas may have important consequences for water consumption and canopy management.

7.3 Effect of Temperature on Vine Growth and Development

Climatic changes like temperature, sunshine hours and unseasonal rainfall can cause shifts in grapevine growth stages that are observable in terms of phenological events, such as budburst, flowering, veraison, harvest and then in yield as well. These seasonal changes to a greater extent can influence the formation and ratio of sugar and pro-phenols in grapes, thereby affecting the quality of produce. In a study covering 18 years of data collection, the percentage of fruitful buds in Thompson Seedless (TS) correlated highly with air temperature and hours of sunshine during a 20-day period at the beginning of a season (Baldwin 1964). This critical period corresponded to growth stages 13–18 of the modified Eichhorn and Lorenz system (Coombe 1995). When air temperature alone was varied in a growth chamber study (Buttrose 1969), bud fruitfulness of Muscat of Alexandria rose from zero at 20°C to a maximum close to 35°C and was followed by a steep decline beyond 35°C. Varieties differ in tolerance to temperature as is evident from the results of Kadir (2005) who subjected four European (*Vitis vinifera* L.) wine grape cvs., Semillon, Pinot Noir, Chardonnay, and Cabernet Sauvignon, and one American (*Vitis aestivalis* Michx.) wine grape cv. Cynthiana, to three temperature regimes in growth chambers. In general, the best temperature for shoot and root growth 28 days after temperature treatments was 20/15°C for Semillon, Cabernet Sauvignon, and Cynthiana and 30/25°C for Pinot Noir and Chardonnay. Pronounced reduction in number of leaves, shoots, tendrils, internodes, total leaf area (LA) and total shoot biomass was more in cv. Cynthiana than in the European cultivars. This shows that the European cultivars were relatively more tolerant to high temperature than the American cultivar and they have a potential for production of wines in hotter areas. Optimum temperature for photosynthesis in Sultana leaves is estimated between 25°C and 30°C (Kriedemann 1968; Kriedemann and Smart 1971). However, vine leaves can attain temperatures up to 10°C higher than ambient temperatures (Kriedemann and Smart 1971). Shaulis (1966) had suggested that under conditions of higher temperatures (42°C) vines are not capable of utilizing radiant energy possibly because the degradation of enzymes and chlorophyll exceeds rate of photosynthesis (Kliewer 1968).

The annual succession of phenological stages of grapevines is commonly observed to be accelerated with a rise in temperature (Alleweldt et al. 1984; Jones and Davis, 2000; Chuine et al. 2004; Duchêne and Schneider 2005; Wolfe et al. 2005; Webb et al. 2007). Such observations show a consistent trend towards earlier flowering, veraison and harvest. The timing of veraison may be of particular importance, because earlier veraison implies that the critical ripening period shifts towards the hotter part of the season. This has already been described for Alsace, France, where the period between budburst and harvest has become shorter, and ripening is occurring under increasingly warm conditions (Duchêne and Schneider 2005). Because ripening grape berries are designed to minimize transpirational water loss (Radler 1965; Possingham et al. 1967; Blanke et al. 1999; Rogiers et al. 2004), they cannot take advantage of the evaporative cooling mechanism that protects leaves from overheating. Thus, while high temperatures tend to accelerate grape ripening, too much heat can inhibit or even denature berry proteins, and may lead to symptoms of sunburn. Model calculations performed for Australian wine regions also project a forward shift in harvest date, which was arbitrarily defined as grapes reaching soluble solids content of 20°Brix (Webb et al. 2007).

In Baden (southwest Germany), the yearly average temperatures of the last 10 years were 1.2°C higher than the average of 1961–1990 (Sigler 2008). The average dates for the beginning of maturation of Pinot Noir in Baden had advanced by 3 weeks from 1976 to 2006 (Sigler 2008). In the Palatinate (Germany), annual average temperatures increased by 1.2°C from 1970 to 2005 and harvest advanced 2 weeks (Petgen 2007). In coastal California areas, average annual temperature increased by 1.13°C and the start of the growing season advanced 18–24 days between 1951 and 1997 (Nemani et al. 2001). From the above findings it is evident that drought stress caused by higher evaporative demand due to rise in temperature may override beneficial effects of increased CO_2 in the atmosphere unless irrigation can be stepped up to compensate. Moisture stress reduces photosynthetic activity in grapes (Kriede-mann and Smart 1971; Liu et al. 1978). Higher frequency of extreme temperatures in summer will automatically lead to increased evapotranspiration which coupled with reduced precipitation may render full or partial use of cover crops impossible in vineyards. The cover crops compete for moisture with the vines and off-flavour problems in white wine have been linked to competition problems for water and nitrogen between cover crop and grapevines in dry years (Rapp et al. 1993). As per available information, 1 mm increase in pan evaporation will increase the irrigation requirement by 4200 l/ha/day during the vegetative and berry development stage if saline irrigation water is used for irrigation (Sharma et al. 2008) under central Maharashtra conditions. Cooler areas like Nasik may benefit from warm night-time temperatures. Development of salt-tolerant and drought-tolerant rootstocks, heat-tolerant varieties and technologies to deal with the heat and salinity stress is essential, but it is a time-demanding process. Until new varieties/technologies develop, the emphasis is to be given on management of crop production techniques with the available technologies.

7.4 Effect of Ultraviolet Radiation Levels on Grapevine Physiology and Grape Composition

As part of those changes in climate and rise in temperature, there will also be changes in solar radiation and levels of UV-B radiation will probably continue to rise. The impact of UV-B on higher plants includes decrease in leaf expansion (Tevini and Teramura 1989) and reduced fresh and dry weight, total biomass and photosynthetic capacity (Krupa and Jager 1996). The effects of UV-B could accumulate from year to year in long-lived perennial plants such as trees (Madronich et al. 1998), and thus, there is a chance that this may also occur in grapevines.

The effects of solar radiations will have marked effect on berry pigmentation and wine flavour and composition. Flavour development will be affected via alteration of secondary metabolites such as flavonoids, amino acids, terpenoids, alcohols and carotenoids. Some key enzymes involved in flavonoid biosynthesis (chalcone synthase) and the phenyl-propanoid pathway (phenylalanine ammonium-lyase) in many crops have been shown to be unregulated by UV radiation, as are levels of key antioxidants glutathione and ascorbate, whereas carotenoid pigment formation and the incorporation of nitrogen into amino acids (AA) can be inhibited (Dohler et al. 1995; Tevini 1996; Jansen et al. 1998). Since components such as flavonoids, amino acids and carotenoids are important constituents of grapes with a marked effect on flavour development, some influence of UV-B radiation on grape composition can be expected (Schultz et al. 1998). On the molecular level, UV-B can destruct peptides and lipids and can photodegrade the plant hormone auxin which absorbs in the UV-B range and may play a significant role in the formation of an off-flavour in white wines that is increasingly found over the last decade in Central Europe (Gebner et al. 1999).

Solar radiations will have marked effect on berry pigmentation and wine flavour and composition. Rising CO_2 concentration alone may increase grape production and water use efficiency, but more comprehensive studies predict decreases in yield when increasing temperature and changes in solar radiation are considered simultaneously.

Viticulturally relevant consequences may also stem from the effect of UV-B radiation on exposed fungal vine pathogens (Keller et al. 2003), which tend to be more susceptible to UV-B radiation than higher plants (Caldwell et al. 2007), as well as herbivorous insects and disease vectors (Caldwell et al. 2007), either directly or mediated by an altered chemical composition of the vines. Caldwell et al. (2007) reviewed works that described the improvement of frost tolerance from UV-B in several plants. With regards to grape aroma, major effects may stem from changes in the composition of phenolic compounds (Schultz et al. 1998; Lafontaine et al. 2005), which play a significant role as photo-protective pigments in vines (Caldwell et al. 2007), and as antioxidants, colour, aroma and mouthfeel-relevant compounds in wines. Schultz (2000) reviewed some examples of possible UV-B radiation-mediated consequences, but the overall effects of increased UV-B radiation levels remain understudied.

7.5 Carbon Sequestration Potential of Grapevines

Carbon sequestration plays an important role in the global carbon cycle. Carbon sequestration can be defined as the retention of carbon to prevent or delay its release to the atmosphere as CO_2. Plants are considered a “sink” for CO_2 because they uptake this gas during photosynthesis. Because plants assimilate carbon, enhancing their populations helps limit atmospheric concentrations of carbon dioxide. Perennial plants are particularly efficient at carbon sequestration because carbon is stored in permanent structures. Every year on a global scale, a very large amount of carbon dioxide (on the order of 100 billion metric tons) is sequestered. At the same time, carbon is released to the atmosphere from vegetative respiration, combustion of wood as fuel, consumption of biomass for food and natural decay. The net numerical difference or flux between carbon sequestration and release can be viewed as measure of the relative contribution to biomass to the carbon cycle.

The biomass production in Indian vineyards under double-pruning and single-cropping system is estimated to be 4.0–5.0 t/ha/year for leaves and canes and 5.0–6.0 t/ha/year for dry fruit yield. In grapevine orchards producing 4.0 t/ha of dry matter, CO_2 equivalent has been estimated to be 8.0 t/ha (Nendel and Kersenbaum 2004) in New Zealand. Taking these figures into consideration, the CO_2 sequestration in the Indian vineyards under double-pruning system can range from 18 to 22 t/ha/year. These figures do not take into account the carbon stored in the permanent vine parts. Considerable carbon is sequestered in the perennial vine parts like trunk, roots and cordons. Carbon dioxide sequestration in vineyards can further be increased by the use of green manuring and cover crops. Data on net numerical difference or flux between carbon sequestered and released as result of decomposition of pruned material and grapes are not available.

7.6 Indian Viticulture: Where Are We?

Documented information in context of impact of climate change on Indian viticulture is not available. Nevertheless, preliminary information gathered based on field visits, etc. gives indication of possible impact of the climate change on viticulture.

7.6.1 Effect of Climate on Grapevine Phenology, Yield and Quality

In India, majority of the grape-growing areas follow single-cropping and double-pruning system. Cost of cultivation is more in these areas as compared to temperate viticulture, because plants remain active throughout the year and need to be maintained. The delay in sprouting during foundation pruning particularly in late-pruned vineyards (pruning done during and after 4th week of April) results in delayed cane maturity and less number of degree days available for proper bud differentiation particularly if this period coincides with the rainy and/or cloudy weather. High temperature after foundation pruning delays bud sprouting in Thompson Seedless vines grafted on Dogridge rootstock. Vines pruned on 10 April 2008 took 20–25 days for initiation of bud sprouting when temperature ranged from 39.0°C to 41.1°C during the second week after pruning compared to 12–15 days (pruned on 23 April 2008) when the temperature ranged from 35.9°C to 38°C during the second week after the pruning in April (Sharma J and Taware PB, unpublished data). Application of hydrogen cyanamide (bud dormancy-breaking chemical) did not have any effect on promoting early bud sprouting in the vines pruned on 10 April 2008.

Warm night-time temperatures are important for table grape yields, with an optimum average minimum temperature of approximately 17.5°C. Warm night temperatures in December–January may accelerate growth during veraison, which may shorten the lag phase in berry growth and thus allow berries to grow larger with more time spent in active growth. This is particularly important for areas like Nasik, where the night-time temperatures are generally less than 10°C during berry development stage, and the grapes are harvested after about 150 days after flowering. In areas like Sangli and Solapur where night-time temperature are comparatively higher (>10°C), the grapes are ready for harvesting in 130–140 days. Night-time temperature in certain locations like Niphad and Vani drops sometimes below 1°C. Severe frost damage has been observed in some of the vineyards in 2008 and in Dindori and Pimpalgaon areas during the year 2012 leading to severe damage to developing vegetative and cluster tissues thereby resulting in severe crop losses. Rise in night-time temperatures will decrease the risk of frost damage in such areas.

When the day temperature is high, exposure to sunlight during berry development and ripening results in berry discoloration (sunburning) thereby affecting the market acceptability. Berry discoloration due to high temperatures and exposure to sunlight is more severe and common in raisin-producing regions like Sangli, Pandharpur and Solapur where the temperatures are comparatively hotter and climate is drier compared to Nasik region which is comparatively cooler. High diurnal variations and low temperatures have been found to increase the incidence of "pink berry" disorder in white grape varieties like Thompson Seedless and its mutants. Use of shade nets and covering the grape bunches with paper bags have proved an effective tool in minimizing the berry discoloration problem.

7.6.2 Effect of Climate on Grapevine Water Requirement, Nutrition and Soil Quality

Indirect effect of increasing temperature could lead to low water availability and increased salinity if it is coupled with decline in precipitation. The drought stress caused by higher evaporative demand due to rise in temperature may override beneficial effects of increased CO_2 in the atmosphere unless irrigation can be stepped up to compensate the water requirement of the vines. Leaf blackening and degradation of chlorophyll has been observed in recent years as a result of high temperatures (exceeding 30°C) during berry ripening in many grape-growing areas of India. The berry weight is reduced in the vines exhibiting the symptoms. The incidence is more in leaves facing sunlight directly for longer duration. Preliminary studies on green and chlorotic leaves present on the same vine revealed that potassium concentration was reduced greatly in leaves suffering from sunburn and the severity of blackening increases with the moisture stress (Sharma J, unpublished data).

Due to rise in temperature, the evaporation from the soil surface will increase leading to the accumulation of salts on the soil surface. The combination of drought and salinity will affect the nutrient availability to vines adversely. In heavy soils, where drainage is restricted and rainfall is less, use of saline irrigation leads to potassium deficiency and toxicity of sodium and chloride causing leaf blackening and necrosis. This reduces fruitfulness and yield and can even lead to death of perennial vine parts (Sharma et al. 2010, 2011). These symptoms are commonly observed and develop much earlier in hot and drought-prone areas such as Solapur, Sangli and Bijapur where groundwater is saline and rainfall is low compared to Nasik region where temperatures are comparatively mild and total rainfall received is higher. Although grape growers have adopted drip irrigation system, considerable moisture is lost as evaporation from soils having poor infiltration/compaction. These evaporative losses can further increase with rise in temperature under climate change. These evaporation losses can be minimized by subsurface irrigation, use of mulches and reducing transpiration losses with the help of antitranspirants. Application of drip water below surface from the existing surface irrigated drip system resulted in higher water use efficiency (Sharma et al. 2005, 2011). Use of mulches and antitranspirant (antistress) resulted in 25% saving of water when compared to surface drip irrigated vines (Upadhyay et al. 2006).

7.6.3 Effect of Climate Change on Indian Wine Industry

In wine grape there is a possibility of taking two crops in a year cycle to increase total annual yield, without compromising wine quality. Especially white varieties like Sauvignon Blanc and Chenin Blanc, which mature within 110–120 days, can produce two yields in a year. Rise in temperatures during cooler months of the year in our present climatic conditions will help such cropping system due to possibility of reducing the ripening period. However, based on the information generated elsewhere, the rise in temperature will demand more electric supply to maintain the desired temperature during fermentation and storage of wines taking into consideration the present wine-processing season in India. It will require more investment in the wine industry and the production cost will increase. Further, as sugar content is likely to increase with accelerated ripening, climate change will lead to wines with modified sugar/acid ratios unless acid is added back to the must (Duchene et al. 2010). Increased sugar concentrations may cause growth inhibition or lysis in microorganisms. This is turn, may result in sluggish alcoholic fermentations, whose occurrence have been reported to increase drastically in hot years (Coulter et al. 2008), and pose a significant problem to the wine industry. Also, under high temperatures during harvesting, vine metabolism may be inhibited leading to reduced metabolite accumulations, which may affect wine aroma and colour. Musts with high sugar concentrations cause a stress response in yeast, which leads to increased formation of fermentation coproducts, such as acetic acid. If not controlled by acid addition, the higher pH can lead to significant changes in the microbial ecology of musts and wines and increase the risk of spoilage and organoleptic degradation (de Orduna 2010).

To prepare for the future, the wine industry should integrate planning and adaptation strategies to adjust accordingly. To facilitate planning for and adaptation to climate change, focused research is needed in two main fields: production of finer-resolution climate simulations more appropriate for assessing microclimates critical for grape growing and improved viticulture modelling-incorporating treatment of varietal potential, phenological development, and vine management and carbon sequestration. The industry may choose to preserve its current wine styles, based on well-known varieties grown in particular climates, and move to the present cooler regions.

7.6.4 Effect of Climate Change on Disease Incidence and Pattern

Anthracnose, a fungal disease, appears only on tender shoots, while bacterial leaf spots (*Xanthomonas sp.*) are seen on old leaves. Both diseases require warm humid conditions for its rapid development. In Maharashtra, during summer showers (May) or early monsoon showers (June), warm and humid climate is present, but most of the time, leaves are not mature and there are plenty of young shoots present in the vineyards. Under these conditions, high incidence of anthracnose is observed but not of bacterial leaf spots (Sawant and Sawant (2008) Effect of rise in temperature and changing climate on disease incidence pattern (personal communication)). During September–October, relatively hotter grape-growing areas (Hyderabad, Latur, Osmanabad, Solapur) receive rain from north-east monsoon. During this period, leaves are matured and many times near senescence and weather is warm and humid. Under such weather conditions infection of bacterial spots is commonly observed instead of anthracnose. Immediately after forward pruning in October, new shoots emerge and warm and humid climate continues till November. Now instead of bacterial leaf spot, anthracnose is seen on shoots, if it rains.

In the event of hot weather likely to prevail even during August and early November, bacterial spots are likely to increase during this period. Bacterial spots in warmer areas contribute to premature leaf drop before forward pruning. Early appearance of bacterial leaf spot due to warm temperatures will increase the chances of leaf drop. Similarly, if warm temperatures prevail during November, bacterial infection can be seen on inflorescence causing direct yield loss. Unlike fungal diseases, bacterial diseases are difficult to control, as effective chemicals are not available. The bacterial infections in grapes are under control due to present climate and suitable pruning timings. This advantage is likely to be gradually reduced due to warm weather and bacterial infections will become prominent. In above-mentioned grape areas, bacterial infections on pomegranate plants are causing serious problem and as yet do not have effective solution. Grape may face same fate if warm temperature prevails for long duration.

Downy mildew infections can occur in a wide range of temperatures if wet condition prevails. Rains during September–October will lead to downy mildew infection on leaves which will cause leaf drop before forward pruning, while wet conditions after forward pruning can increase downy mildew on young shoots and bunches causing yield loss. Bacterial infection will also be increased due to downy mildew infection. Recently the decline in grape productivity is attributed mainly to the unseasonal rains leading to heavy downy mildew incidence. This has further led to change in pruning time. In fact in some areas, the pruning time has shifted from October to November. But this shift could affect the berry growth as berry setting stage coincides with low temperatures.

There is a practice of early fruit pruning in many areas such as Satana in Nasik district and Bori in Pune district. Early pruning is taken to bring the grapes in market during November and December and to get good price. Such a pruning practice became common due to rain pattern in this area. It is interesting to note that in Satana area fruit pruning is taken from June 15th onwards. During early monsoon months, there are very scanty rains and maximum temperature remains above 30°C for a long time. Due to such high temperatures even if it rains, downy mildew does not develop on new shoots. In vineyards pruned during June–July, downy mildew is not developed or remains within manageable limits. While in vineyards pruned after July, downy mildew management becomes more and more difficult as maximum temperature drops below 30°C as more rains are received. Earlier, it never rained after October, and hence, harvesting during November, in case of above-mentioned vineyards, was very safe. However, during the last 2–3 years, rains during November and December have become regular feature. These rains cause heavy damage to harvestable crops in early pruned vineyards. Direct losses due to hail storms or cracking of berries due to high relative humidity are the major problems in such crops. Even minor rain during November and December period reduces the shelf life of the crop substantially due to post-harvest rots; thus, growers do not get good price.

7.6.5 Effect of Weather Factors on Insect Pest Incidence

The last two decades of grape cultivation in India witnessed sea change in insect pest scenario. Girdler beetle which was major pest in grapes became minor one and minor pests such as thrips, mealy bugs, red spider mites and stem borer became major. Moreover, jassids, scale insects, caterpillars, flea beetle and chafer beetle have potential to become major pests in near future. Outbreaks of red spider mites in Sangli and Solapur districts of Maharashtra during March–April 2011 and jassids in Nashik district of Maharashtra during November 2011 in grapes are the recent examples. This shift in pest scenario may be attributed to change in climate and cultivation practices. Insects and mites are cold-blooded organisms which mean that their body temperatures are approximately the same as that of the surrounding environment. Therefore, temperature is most important environmental factor determining insect life cycle and multiplication. Insect life cycle forecasting studies are calculated using thermal constant. It was estimated that increase of 2°C temperature can result in one to five additional generations per season (Yamamura and Kiritani 1998). The moisture and CO_2 effects on insects may also be important in climate change scenario as estimated by Coviella and Trumble (1999), Hunter (2001) and Hamilton et al. (2005).

Crop-growth-stage- and degree-day-accumulation-based models can be used to predict the development of insects and mites. Increase in temperature within favourable range can increase the rate of development of insects. In case of natural enemies, increase in temperature may lead to reduced parasitism if host populations pass through vulnerable life stages more quickly thus reducing the parasitism period. Temperature may also affect gender ratios of thrips (Lewis 1997) thereby affecting reproduction rates. Increase in temperatures may also lead to lower winter mortality of insects which can finally result in higher population levels (Harrington et al. 2001).

Future strategies for mitigation of effect of climate on insect and mite pest complex include development of automatic decision support system based on weather forecasting with the aim to give advisory to farmers on daily basis through the World Wide Web. Mealy bug population build-up was found to be coincided with increase in temperature, decrease in the humidity and advancement in the berry development. Thrips population was negatively correlated with minimum temperature ($r = -0.72$) and rainfall ($r = -0.43$). Results also indicated that the mite population increased from 4.20/leaf in December to 24.20 mites/leaf and it was negatively correlated with minimum temperature ($r = -0.48$) and relative humidity ($r = -0.65$) in Pune conditions (Anonymous 2009).

7.7 Mitigation Strategies and Future Researchable Issues

Majority of the grape cultivation in India is concentrated in the agro-ecological region (K4Dd3) with the mean annual precipitation ranging between 600 and 1000 mm, covering about 40% of annual PET demand (1600 and 1800 mm). This results in gross annual deficit of 800–1000 mm of water. Grape-growing regions comprising of districts of Ahmednagar, Beed, Solapur, Sangli (eastern parts), Satara (eastern parts), Osmanabad and Latur in Maharashtra state and Bidar, Gulbarga and Bijapur in Karnataka state constitute drought-prone areas. Severe drought spells repeat once in 3 years. The moisture availability mostly remains as submarginal (Gajbhiye and Mandal 2006). Moisture and temperature stress affects not only the growth and yield of crop but also its quality.

Increased temperature increases the irrigation demand evaporation rate thereby increasing the optimum soil moisture that should be maintained to mitigate the effects of rise in temperature. Own-rooted vines suffer most due to limited root system during drought. To deal with salinity and moisture stress, vines should be raised on rootstocks like Dogridge and 110R. The evaporation losses can be minimized by subsurface irrigation, use of mulches and transpiration losses with the help of antitranspirants. Application of drip water below surface from the existing surface irrigated drip system resulted in higher water use efficiency (Sharma et al. 2005, 2011). Use of mulches and antitranspirant (anti stress) resulted in 25% saving surface drip irrigated vines. Similarly use of mulching and antistress (an acrylic polymer) mulching could result in 25% savings in surface drip irrigated vines (Upadhyay et al. 2006). The existing rootstocks like B-2/56, 110R and 1103P have better sodium exclusion ability than Dogridge and Salt Creek; hence, in areas having sodicity problem, they should be preferred (Anonymous 2009; Sharma et al. 2011).

The architecture of horticulture and crop plants, as well as trees, is influenced by endogenous factors such as hormone signals and trophic competition between organs but also by exogenous factors such as light distribution, temperature, soil water and nutrient regimes. Plant morphology can also be artificially modified by humans through agronomic practices, such as pruning and training (Guo et al. 2011). Canopy management strategies like growing more leaves in hot years to shade fruit, leaf removal on southeast or eastern side of canopy to capture the morning sun, shoot positioning on northwest or western side of canopy to shade fruit in the hot afternoon and managing water to retain differential leaf cover avoid heat stress. Use of shade nets helps in minimizing the heat damage. Shade nets are being used by the growers to minimize the heat injury to vines particularly for grapes grown for export market.

Carbon dioxide sequestration in vineyards can be increased by the use of green manuring, cover crops and incorporation of crop residues. More carbon is likely to be sequestered as a result of increased root biomass under elevated CO_2. However, at present the growers are reluctant to use pruned biomass due to apprehension of increased incidence of downy mildew and insects like borers. Similarly, cover crops and green manure crops will compete with vines under moisture scarcity conditions. However, in areas where irrigation water is not a limitation use of green manuring, cover crops and incorporation of crop residues will be beneficial. Methods to minimize rise in soil temperature, e.g. maintaining optimum soil moisture and mulching, may help in reducing the decomposition rate of the soil organic matter thereby reducing the CO_2 emissions.

Uncertainty of weather is a major factor associated with losses in vineyards. In grape-growing areas, rarely continuous heavy rains are received. Whenever such rains were received, there were heavy losses in vineyards due to diseases and physiological disorders. But in majority of the situations, disturbance due to untimely rains is very less and can be managed if forewarning about the weather disturbances are received and proper guidance on disease management is made available. During the rainy season, especially after fruit pruning, growers tend to spray fungicides excessively. Most of the sprays are followed by rains which results in not only washing off of the fungicides but poor systematicity due to high RH and low transpiration pull. Therefore, in spite of heavy spraying, effective control of downy mildew is not achieved. Managing through preventive sprays well before the rains and following up with sprays after the rainy weather is over can lead to better efficacy of fungicides. However, it is possible only when possibility of rains is forecasted correctly. Recently, technology for location-specific short-term weather forecast is available. National Research Centre for Grapes, Pune, has developed automated online system to generate location-specific weather advisory on a daily basis for management of downy mildew. Such system can be effectively used for management of downy mildew in the event of untimely rains. In many areas, the pruning time has shifted from October to November, thereby leading to better downy mildew management.

7.8 Future Research Needs

- Development of heat-tolerant grape varieties, salt- and drought-tolerant rootstocks and technologies to deal with the heat and salinity stress is essential, but it is a time-demanding process. Until new varieties/technologies are developed, the emphasis is to be given on management of crop production techniques with the available technologies.
- The availability and quality of the irrigation water will be deciding overall impacts of climate change. Research on subsurface method of drip irrigation to determine the depth of application (discharge point) for different rootstocks to further improve the water use efficiency using saline irrigation water is needed.
- There is a need for research on agro-techniques to minimize decomposition of soil organic matter and increasing the carbon sequestration by use of cover crops which do not compete with grapevines for nutrients and moisture and do not increase the disease and insect pest incidence. There is a need for standardization of location-specific and variety-specific agro-techniques.
- Although historical and projected average temperature changes are known to influence global wine quality, the potential future response of wine-producing regions to spatially heterogeneous changes in extreme events is largely unknown. Effect of change in temperature and precipitation on vine growth, berry composition and development and wine quality needs to be studied to modify the vineyard and vinification processes accordingly.
- Studies to establish relationship between temperature and phenology of grapevine and its impact on grapevine productivity are needed.
- Impact of temperature and water stress at molecular level is not well understood. The knowledge of grape genome sequence provides an opportunity to identify the genomic regions imparting tolerance to abiotic stresses. Functional genomics of abiotic stress through whole transcriptome analysis needs to be studied to identify genomic regions involved in stress response.

7.9 Conclusions

Sustenance of today's grape-growing regions will depend on how well we adapt to this situation and mitigate the effects of climate change. The impact of climate change will vary from region to region across the country. A hotter climate would bring variation in quality of both table and wine grapes. In some of the regions, however, the temperature of the ripening period may become too hot to produce balanced wines from some or all grape varieties. Rise in temperature of ripening period in particular is likely to affect berry development and their composition in table grapes also.

Grapes in arid regions may benefit from increased CO_2 and may partly overcome some of the adverse conditions created by drought. Faster development of larger leaf area under elevated CO_2 levels may in turn have important consequences for water consumption and canopy management, which is difficult to predict when several climatic factors are to be considered. However, in the event of environmental stresses like drought, grapevines may not perform well under increased atmospheric CO_2. The elevated CO_2 levels may increase productivity in arid and semiarid regions, but the drought stress caused by higher evaporative demand may override beneficial effects of increased CO_2 in the atmosphere unless irrigation is increased to compensate the evaporative demand. The availability and quality of the irrigation water will decide the overall impacts of climate change. The impact on viticulture would be dramatic, especially in areas like Sangli, Pandharpur, Solapur, some parts of Nasik, Hyderabad and Bijapur where water is a scarce resource.

In view of climate change, varieties have to be replaced and/or the management strategies have to be changed. Development of heat-tolerant grape varieties, salt- and drought-tolerant rootstocks and technologies to deal with the heat and salinity stress is essential, but it is a time-demanding process. Until new varieties/technologies are developed to improve water use efficiency and cope up with salinity, the emphasis has to be given on management of crop production techniques with the available technologies like subsurface irrigation, mulching, use of drought-tolerant rootstocks, antitranspirants, and shade nets. There is likelihood of change in the incidence and pattern of insect pests like mealy bug, thrips and mites. Similarly the disease incidence pattern is also likely to be affected with the change in climate.

There has been a huge historical and cultural identity associated with wine grape-producing regions all over the world. As a result of climate change, a region known for a particular variety, for instance, might need to shift to another kind of grape variety, changing the cultural identity that has developed over centuries. A hotter climate would also change the timing of harvest and ripening. Changes in cropping season to adjust to changed climate will bring market competition-related issues particularly for Indian table grape industry in domestic as well as global markets.

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8

Climate Resilient Adaptation Strategies for Litchi Production

Rajesh Kumar and Vishal Nath

Abstract

Litchi is very fastidious in its climatic requirements. Its cultivation and commercialization globally has therefore been at slow pace due to this stringent requirement. It is observed that there is poor as well as erratic bearing pattern in trees in many important litchi-growing areas. The growth, panicle emergence time, flowering behaviour and flowering phase have been found to be influenced by the impact of climatic change. The productivity/yield and quality fruit production have also been found to be very much affected by environmental parameters like temperature, photoperiod/light intensity, moisture content in the soil and humidity in the atmosphere.

In an era of dynamic climatic changes, there is a strong need for adaptation strategies to be implemented with efficient water-nutrient management, canopy management and integrated pest management (IPM). The present assessment is based on the study carried out at NRC for Litchi, Muzaffarpur, and Bihar where practice of nonselective corrective pruning and reiterative pruning has been adopted for canopy development and enhanced quality production as well as for rebuilding of canopy even in unproductive old senile orchards. Based on this success, proper and timely pruning and training techniques have been standardized for canopy development and influencing microclimate for successfully combating the variable climatic conditions. The resilient adaptation strategies for successful litchi cultivation interalia include use of (1) windbreakers for avoiding damage by heavy windstorm, (2) better root stocks, (3) canopy management, (4) girdling, (5) rejuvenation of old unproductive orchards, (6) mulching and (7) honeybees as potential pollinators. The skilful use of adaptation strategies at appropriate time is the key for successfully overcoming the ill effects of climatic changes.

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As litchi has very narrow genetic base, it provides an ideal opportunity for developing climate analogous software, which could be adopted for litchi cultivation in country's different climatic zones for benefit of the farmers. A start has already been made by developing IT-enabled "frost alert system" software which uses forecast system to mitigate the ill effects in litchi production owing to vagaries of climatic conditions.

8.1 Introduction

Litchi (*Litchi chinensis* Sonn.) is an important, evergreen subtropical fruit crop (family Sapindaceae) of India. Its production in this country has undergone substantial expansion in the past 50 years with plantations increasing from 9,400 ha in 1949 to 60,000 ha in 2008. Now this crop has attained the status of important commercial fruit crop of India. Fruits are available from early May to early July in different areas, with only a small quantity being exported in the last few years. The commercialization around the world has been slow due to specific climatic requirement for successful cultivation and poor as well as erratic cropping pattern in many areas. Litchi plantation is found concentrated mainly in eastern states like Bihar, W.B. and U.P., with less concentration in Jharkhand, Tripura, Orissa, Punjab, Haryana, H.P., Assam and the Nilgiris hills (20–27°N latitude). The productivity and quality fruit production in litchi are strongly affected by environmental parameters like temperature, photoperiod/light intensity and moisture content in the soil and humidity in the atmosphere.

8.2 Impact of Climate Change on Growth and Productivity

Litchi requires specific but mild climate for its successful production. The growing season, thermal time (temperature range), moderate winter, actual rainfall with its specific annual distribution pattern and several of the interaction variables considerably influence the phase change in the annual cycle of the plant (Menzel and Waite 2005). Variability in weather conditions, like increase in temperature and moisture stress conditions during critical stages of crop, causes heavy yield loss and adversely affects the fruit quality even under adequate management conditions.

Due to the climate change, the increase in temperature and variability in precipitation pattern could lead to the development of abiotic stresses like heat, drought and flooding (Boyer 1982). These stresses occur in varying intensities coinciding with different growth and development phases of the crops, finally determining the productivity and quality. The air temperature, heat waves and frost are decisive factors in plant growth and development in litchi. Similarly, an assessment of the impact of elevated CO_2 in conjunction with increasing temperature needs to be studied for this specific crop (Menzel and Waite 2005).

In India, the salubrious climatic conditions for litchi cultivation is found restricted in the foot hills of Himalayas from Tripura to Jammu Kashmir and plains of Uttar Pradesh and Madhya Pradesh, though commercial cultivation have been found confined mainly to Bihar, West Bengal and Uttaran-chal. Globally, the ideal climatic condition for litchi wrt production and productivity varies considerably (Rai et al. 2001). The unusual impact of climate change has been witnessed in litchi production system as noted in flowering pattern (shifted early), fruit growth and harvesting period. The occurrence and the extent of damage by physiological disorders and resurgence of pests are very much dependent on the temperature and humidity variations in the atmosphere. The aberrant weather and extreme events may damage the crop completely.

The imbalance in climatic parameters, threatening the sustainability and the adverse effect/impact needs public intervention and also preparedness to face the challenges. It is required to have quick and clear understanding of impacts of climate

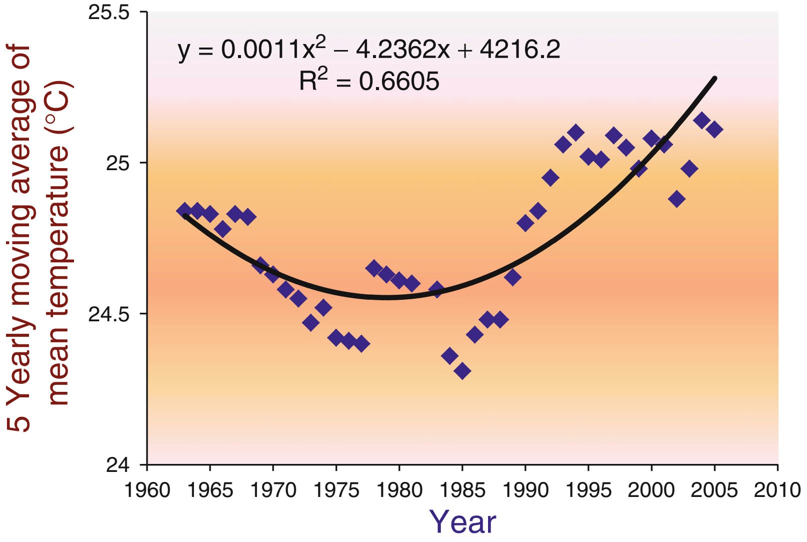

Fig. 8.1 Temperature trend at Samastipur (Bihar) (Source: Agro-meteorology division, RAU, Pusa, Bihar, India)

change on litchi crop for making sound action plan. The evergreen perennial litchi as sole crop or litchi-based farming systems also has very high potential for sequestering carbon for mitigation of climate change.

8.2.1 Temperature

The effects of temperature on growth and productivity for various litchi-growing areas have been extensively studied (Menzel et al. 1989; Menzel and Simpson 1995). As litchi is adapted to the warm subtropics and all the phenological changes are associated with certain specific temperature (range) requirements. The variation usually influences the fruit size and maturity as well as quality. Cropping is best in climates with hot humid summers and dry cool winters. Flower initiation in litchi is best below 20°C, while the optimal temperature for leaf and fruit growth is about 30°C. Temperature below 2°C damages new leaves, while below 0°C can kill the trees (Menzel and Waite 2005). There is a rapid period of shoot elongation and leaf expansion followed by a period of leaf maturation before the next period of shoot growth. The duration and interval of growth have been found to be related to temperature. The environmental adaptability of this crop has confined commercial production mainly to subtropics, where annual temperatures vary markedly across this range of latitude (regions). In major litchi-growing regions of the country (Bihar, W.B. and Uttaranchal), the less dependable is flowering, this is because cool temperatures are necessary for floral induction. The processes influencing floral initiation and bloom in litchi are elucidated by Davenport (2000) through a model proposing reproductive induction by vegetative and floral promoters (phytohormones) governing the type of shoot initiation, which is very much influenced by the environment mainly temperature. Better fruit set, fruit development and yields occur when temperature approaches from low (restricting vegetative phase) to warmer days and nights (allowing flower development and pollination), then again the higher range for fruit development and maturity (Davenport 2003).

Global warming will have negative impact on subtropical regions, as the prevailing temperatures during the season are shifting towards higher side. Characterization of temperature trend over Bihar (Pusa, Samastipur) was done over a database for 50 years (1960–2010) having monthly mean and minimum temperatures (Fig. 8.1). This clearly indicated an increasing trend over this place with a clear indication that local climate is undergoing change (Sattar 2010). The observed temperature trend in the region of litchi production (Bihar) showed a general increase in temperatures in order of 2–3°C over the base period of 50 years, while the reports are available that an average increase of 1–2°C could affect the phenology of this crop by influencing the degree days and it may respond differently, as occurrence of abnormal temperature has been a recurring phenomena in recent years, which certainly affects the prospect of litchi production and productivity.

8.2.2 Light Intensity and Photoperiod

The litchi crop is very much responsive to the light intensity and photoperiod for quality fruit production. The varied level of net CO_2 assimilation was recorded in various leaf growth stages as (1) in soft red green leaves 0.3 μmol/m^2/s, (2) in red green leaves 1.6 μ mol/m^2/s, (3) in light green leaves 2.7 μmol/m^2/s, (4) in dark green leaves 5.8 μmol/m^2/s and (5) in fruit growth to maturation 10.0–3.0 μmol/m^2/s. These differences in CO_2 fixation were associated with higher concentrations of chlorophyll in older leaves than in the younger leaves. The presence and absence of fruits on the tree can influence the rate of leaf photosynthesis (Menzel and Waite 2005). Clearly, the amount of CO_2 fixed by plants depends on environmental conditions and the physiology of the leaves. The distribution of light and leaf nitrogen within the tree is usually a good indication of potential photosynthesis. Interaction effect of light, temperature, partial pressure of CO_2 water vapour and leaf water status influences photosynthesis by affecting the opening and closing of the stomata or leaf chemistry. Light used for CO_2 fixation is usually referred to in terms of photosynthetic photon flux density, PPFD or the number of photons from 400 to 700 nm.

Light may limit flower development in dense orchard. In litchi, high sunshine hours are expected to be correlated with fruit quality. Ultraviolet rays play an important role in the development of colour; more of UV rays reach the plants when atmosphere is free from dust. These help to develop anthocyanin pigments to a greater extent (Singh 2009). Heavy shade for 1 week increases fruit drop. Overall, the productivity is driven by the amount and distribution of light and nitrogen in the tree, along with water supply and temperature. Thus, it is inferred that variation in solar radiation may cause adverse effect on overall quality production and productivity.

8.2.3 Rainfall and Humidity

In litchi, an adequate amount of rainfall is necessary just after the harvest of fruits for proper initiation of new shoots, as current season shoots after proper maturity bear panicle and fruits. The delay in shoot emergence may cause unfruitfulness even in the coming season. Rains during the full bloom period cause washing off of pollens and restrict activities of pollinating insects, which may lead to poor fruit set and fruit yield. The database of monthly rainfall for 20 years (1971–2001) (Fig. 8.2) showed that the maximum rains occur in main monsoon period (July to September) and the rest of the periods were not dependable. The monsoon period mainly coincides with the period of active growth of litchi (Sattar 2010), but premonsoon showers prior to harvest time destroy the quality of ripening fruits. High rainfall and humidity induce good growth, and the average annual rainfall is considered to be around 1,250–2,000 mm for litchi. It is generally observed that abundant rainfall or irrigation and the resulting high soil moisture level encourages vegetative flushing. In India, there are areas where annual rainfall is less than 1,000 mm, but litchis are cultivated on a commercial basis. A dry autumn and winter are important to prevent vegetative growth and making essential condition for good flowering (in south China). A certain degree of water stress is needed for flower initiation. Fruit set in litchi is climate dependent and profoundly affected by humidity in conjunction with other climatic factors. Cloudy weather with increased humidity in the atmosphere encourages the incidence of pests and diseases and interferes with the activity of pollinating insects, thus adversely affecting fruit set. Overall, the optimum rains are conducive for production of quality litchi fruits, but sometimes early and continuous monsoon affects the quality

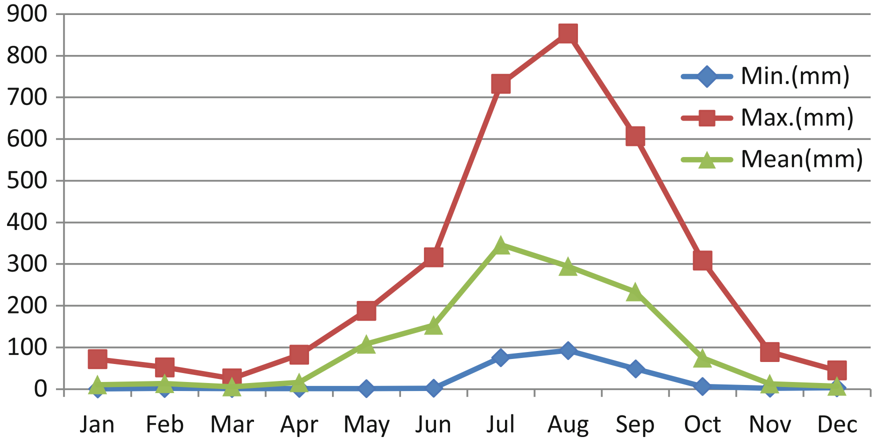

Fig. 8.2 Characteristics of monthly rainfall, Pusa, Bihar (1971–2001)

due to severe attack of fruit borer and some rots. High humidity and heavy rain during aril growth period of fruit development lead to excessive absorption of water by aril (fruit) and may aggravate many disorders like fruit cracking and fruit drop.

8.2.4 Wind

Like other important fruit crops, the initial establishment, proper growth and performance of litchi have been affected by nature of winds. Litchi plantations at initial stages experiencing hurricanes/high windstorms hamper establishment. The dust storm and squalls up to 60–80 km/h experienced in between the period of February to June damage the crop right from panicle development to whipping off of flower and fruits may cause complete crop loss. Heat waves during summer have an adverse effect both on fruit and foliage growth, which is more so in the areas adjacent to open fields that are not fully protected with windbreaks. Wind also leads to a loss of vigour and, consequently, slower growth. The high-speed windstorm or cyclones during fruit-bearing period, more particularly at harvesting time, may cause serious damage. Fruit drop at initial stages of its growth can be noticed due to high wind velocity. Various measures may be taken to limit the damage, but the most recommended is perhaps the raising of thick and strong windbreaks around the litchi orchard.

8.2.5 Fog and Frost

Fog definitely curtails light supply and reduces photosynthesis, while spring frosts are particularly harmful to litchi plants. Frost may either kill the reproductive organs of the flower or completely destroy the blossoms, thereby influencing the fruit set and ultimately the fruitfulness. Litchi young plants are extremely sensitive to cold and require frost protection. Frost has been regarded as one of the important factors responsible for causing drastic effect on bearing behaviour and even leading to mortality of the plants/trees. The extent of damage by frost depends upon age of the tree, moisture content of the soil, condition of growth, actual timing of frost occurrence and severity and duration of the frost. It has been found devastating for litchi, growing in areas/places having mild tropical and subtropical climate. Moist soil or irrigated soil raises the soil temperature and provides protection against mild frost.

8.3 Resilient Adaptation Measures

The resilient adaptation strategies to address the adverse impact of climate change on litchi production and productivity need immediate attention. The adaptation strategies should be planned to increase water and nutrient use efficiency, soil amendments and cultural practices by using modifying the canopy architectural design and use of integrated pest management practices.

Like other commercial fruit crops, litchi too has substantial carbon sequestration potential and strengthens the system ability to cope up with adverse impacts of changing climatic conditions. The influence of prevailing climatic conditions and the ill effects on overall productivity and quality of litchi due to climatic aberrations during the season can be nullified to a great extent by practicing region-specific adaptation measures, which can be (1) root stocks, pruning and canopy management including rejuvenation of old senile orchards, (2) growing intercrops and need-based intercultural operations, (3) use of mulching and recommended type of mulching material, (4) nutrient management with more emphasis on organic farming, (5) water management for enhancing water use efficiency and (6) use of integrated pest management practices.

The use of rootstocks and scion for vigour control and deep root system for litchi needs attention. The seedling rootstocks affect growth and yield of scion cultivars, also influence the photosynthetic efficiency and fruit quality.

8.4 Canopy Management

Canopy manipulations in litchi deserve more attention and importance. Training is practised in litchi mainly to give an open umbrella or semicircular shape of canopy to build a strong framework and induce maximum surface area to bear crop of good quality. The aim of utilizing the available space and sunlight is also fulfilled. Most orchards were planted at aspersing of 10 m × 10 m, i.e. low density and the trees were left to develop into large canopies. However, now the technology of canopy development is spreading fast and new orchards are planted under high densities and are pruned regularly. The technology adoption is increasing but with a slow pace.

Prolonged periods of overcast weather, extremes of temperature and droughts can reduce photosynthesis and productivity of many orchards in growing areas, but the timely pruning and training operation for canopy management have resulted increased productivity with quality production. The efforts to develop pruning and training strategies for high-density orchards with the intention to maximize light interception have given good response. The studies on the effect of pruning intensity on microclimate modification, time of panicle emergence, sex ratio, pest incidence and number of panicles emerged in litchi trees under high-density planting have been found to give higher percentage of healthy panicle emergence, flowering and fruit set as compared to unpruned trees. Maximum fruited panicles appeared at middle portion of the outer canopy than at the top; hence, the technique of centre open as well as nonselective pruning adopted to reduce the height and enhance the canopy spread. Pruning intensities modified microclimate, and the temperature variation observed was to the tune of 2.5°C inside the canopy in unpruned trees in August and March months. The field observations on the flushing time, flowering and fruit set were found better in case of trees received nonselective pruning just after the harvest of fruits. The likely created open canopy increased the pace of vegetative growth and panicle emergence leading to flowering. Reports also suggest that pruning or defoliation stimulates shoots initiation as such treatments not only remove the source auxin production but also increase cytokinin concentrations in Xylem sap (Goren and Gazit 1996; Olesen et al. 2002). Responses of external application of auxin at different time of vegetative flushes in late summer and early winter were found inconsistent, suggesting the need of timely operation of pruning and training.

The unmanaged orchards may develop senility and become unproductive. The rejuvenation of old senile orchards through reiterative pruning and required training for good canopy development can bring back to give quality yield like young orchards with more efficient and optimum input utilization in sustained manner. There have also been some efforts to determine the relative contribution of photosynthesis by examining the effects of light and temperature on CO_2 fixation in the single leaf, leaves and whole tree. These factors are main environmental variables during canopy photosynthesis with increased canopy surface bearing area. Girdling, defoliation and fruit thinning have been used to study the relationship between yield, photosynthesis and stored reserves (Menzel and Waite 2005).

8.5 Water Management

Water functions through both biophysical and biochemical activities in fruit plants and like in litchi too. The sound production strategies like improved water use efficiency under hot and dry conditions should be developed for litchi at its region-specific basis based on the fact that redistribution of organic compounds from source to sink and meristematic regions through movement and circulation of water at its critical stages. Like other fruit plants, the water use efficiency in litchi also varies with phyllo-taxonomic arrangement, ratio of chlorophyll fractions and size and frequency of guard cells in the leaves and ability of water-absorbing organs and also interactions of many other factors. Providing irrigation during critical stages of crop growth and conservation of soil moisture reserves are the most important interventions for bearing behaviour and quality production in litchi. The crop management practices like mulching with crop residues and plastic mulches help in conserving soil moisture. In some instances, excessive soil moisture due to heavy rain and untimely rain becomes major problem, and it could be overcome by growing intercrops, light intercultural operations and raised basin making. Drought has been used to manipulate autumn vegetative flushing and to improve flowering and yield of litchi in Israel (Goren and Gazit 1996).

8.6 Conclusion

Litchi grows well in mean annual temperature ranging from 20°C to 25°C and average annual rainfall of 1,500 mm (uniformly distributed). Having proper and desirable temperature during panicle emergence is crucial for a good harvest. Cool temperature in the range of 8–10°C favours good inflorescence development and flowering in litchi. However, litchi can withstand temperature as high as 44°C during the period of fruit development and maturity. Higher temperature, good sunshine and adequate soil moisture in the rhizosphere aid improved fruit size and quality. The aberrations in weather like prolonged cloudy weather and rains during the full bloom abetting normal cross-pollination (due to diminished activities of pollinators which are mainly honeybees) and fruit set in litchi sometimes may cause total crop failure. In addition, moist weather leads to severe attacks of mites and other insects as well as promotes incidence of lichen growth on the trunk and branches causing bark splitting, leading to other fungus infestation in the litchi crop. Pre-harvest low-intensity sunshine due to cloudy weather reduces the content of ascorbic acid and sugar in the fruit.

As on date information on effect of raised CO_2 levels in the atmosphere and rise in temperature is lacking in India. This aspect needs to be addressed urgently by gathering statistical data from related studies carried out in other litchi-growing countries and extrapolating the same based on Indian conditions for making projections both at regional and national levels. Past adverse climatic change occurrences such as droughts and cyclones have severely affected the litchi fruit yield. The studies undertaken abroad on the litchi simulation-model-based projections indicate the adverse influence of climate change on litchi cultivation. Quality of the produce is also likely to be affected with changes in physiochemical characteristics. Soil moisture conservation needs to be given paramount importance for crop production in water-limiting scenarios for the future. The carbon sequestration potential of these evergreen plantation/trees with dense foliage needs to be exploited for acquiring carbon credits for the overall benefits of farmers.

The influence of prevailing climatic conditions and its ill effects on overall productivity and quality in litchi due to climatic aberrations during the season can be nullified to a great extent by practicing region-specific adaptation measures like (1) pruning and canopy management including rejuvenation of old senile orchards and use of rootstocks, (2) growing intercrops and need-based intercultural operations, (3) mulching and mulching material, (4) nutrient management with more emphasis on organic farming, (5) water management strategically for enhancing water efficiency and (6) integrated pest management practices.

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Impact of Climate Change on Mountain Horticulture

9

Kartar Singh Verma, Mahadev Singh Mankotia,
Sudhir Verma, and Vikas Kumar Sharma

Abstract

The ecosystems which are most vulnerable to the specter of climate change are high mountain areas such as Himalayas. In Northwestern Himalayan region covering the states of Himachal Pradesh, Jammu, and Kashmir besides Uttrakhand, very limited studies on climate change have been done. Hence, considering the past and present climatic trends, future climatic scenario of Himachal Pradesh has been studied. Himachal Pradesh is a mountain state of north India, located between 30° 22′ 40″ to 33° 12′ 40″ N latitude and 75° 47′ 55″ to 79° 04′ 20″ E longitude. It has large dissimilarity in physiographic features and experiencing varied changes in warming and precipitation due to global warming, which will be both negative and positive, to horticulture production. Future climate will determine the suitability of fruit crops to their current locations. Climatic conditions likely to occur in Himachal Pradesh during 2021–2050 are analyzed and termed as mid-period compared to baseline period (1960–1990) using HADRM3 model under scenario A1B. The climatic parameters included are maximum temperature (Tmax), minimum temperature (Tmin), and rainfall. District-wise changes, likely to occur, in the above parameters and their implications to fruit cultivation have been discussed in this chapter.

9.1 Introduction

Horticulture in Himachal Pradesh consists of diverse farming activities, *viz.*, growing of fruits, vegetables, and floriculture, which are cultivated in a wide range of production regions because of the diverse microclimates and soils. All horticultural crops are sensitive to temperature and commercial crops of the state like apple in temperate region and mango in subtropical region

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Table 9.1 Growth in land area under horticulture crops in Himachal Pradesh

Land Area (ha)				
1950–1951				
2006–2007				
1200				
1,97,446				
Percentage of total				
**A.*	*Temperate fruits*	:	*117878*	
	i) Apple	:	91804	77.88
	ii) Other temperate fruits (OTF)	:	26074	22.09
B.	*Subtropical fruits*	:	*68240*	
	i) Citrus	:	21120	30.94
	ii) Mango	:	38370	56.23
	iii) Other subtropical fruits (OSTF)	:	8750	12.82
C.	*Nuts and dry fruits*	:	*11328*	

Table 9.2 Changes in land area (ha) under apple cultivation in different apple-growing districts of H.P. during the last three decades

Districts	1981–1982	2006–2007	Total change in land area (+/ –)	Percent change in land area
Shimla	18,887	30,666	+11,779	62
Kullu	10,264	21,824	+11,560	112.62
Mandi	6,728	14,964	+8,236	122.41
Sirmaur	2,897	3,607	+710	24.51
Kinnaur	2,026	8,457	+6,449	320.78
Chamba	1,582	11,023	+9,441	596.7
Solan	482	112	–370	(–) 76.76
Kangra	416	444	+28	6.73
Lahaul–Spiti	48	684	+636	1325

have specific temperature requirements for their development, optimum yield, and quality. Based on temperature requirements, the fruits grown in Himachal Pradesh can be categorized into subtropical, subtemperate/warm temperate, and temperate fruits. Mango, guava, papaya, litchi, aonla, lime, lemon, and oranges are some of important subtropical fruits. Peach, plum, apricot, persimmon, pear, pecan nut, kiwi, walnut, strawberry, and certain varieties of apple are grouped as subtemperate/warm temperate fruits. These crops have considerable overlap in response to subtropical and temperate climate: Kiwi fruit adapts well in warm temperate regions. The third category of fruits is temperate fruits and requires winter that is cold enough to give buds adequate chilling to break winter rest and a growing season that is long enough to mature the crop. Temperate fruits need a distinct cold dormant period for a satisfactory crop. In Himachal Pradesh, apple is a commercial temperate crop.

The area under fruit crops during 1950–1951 was just 1,200 ha which has increased to about 1.97 lakh hectare during 2006–2007 (Table 9.1). Out of the total area, temperate fruits occupy 1.178 lakh ha. But most of it (0.918 lakh ha) is under apple. About 78% of the area under temperate fruits and 46% of total area under fruits in Himachal Pradesh is under apple.

9.2 Apple Growth Scenario

There are twelve districts in the state, and the apple is being cultivated in the nine districts, viz., Shimla, Kullu, Kinnaur, Lahaul–Spiti, Chamba, Kangra, Solan, Mandi, and Sirmaur (Table 9.2). Maximum increase in area since 1981–1982 was observed in Shimla followed by Kullu, Chamba, Mandi, Kinnaur, Sirmaur, Lahaul–Spiti, and Kangra (Table 9.2). However, Solan lost about 77% of area during this period.

The loss or gain in land area by districts under apple has been the direct implications of increasing air temperatures in mountain regions as a result of global climate change. Apple cultivation in Sirmaur and Solan districts lying in the transitional subtemperate–temperate climate demonstrated very slow or even negative growth. In contrast, Kinnaur and Lahaul–Spiti districts in dry temperate climate experienced a positive growth by bringing more areas under apple crop. Increased air temperatures created more congenial environmental conditions in dry temperate areas, whereas many areas in subtemperate–temperate climatic zones were rendered unsuitable for apple cultivation.

9.2.1 Land Area Versus Production Trends

Apple cultivation in Himachal Pradesh has experienced progressive increase in area since 1965–1970 except during 1985–1995 which was termed as "a sluggish growth period." The area continued to grow between 7,000 and 9,000 ha per 5-year period since 1970–1975 to 1990–1995. Experiencing a very slow increase in total production during the decade of 1985–1995, an additional area of 21,000 ha was brought under apple cultivation. However, fruit production declined to a low of 0.249 m from the level of 0.2746 m. During 2000–2005, the area increased marginally compared to previous years, but the increase in production was all time high. The quantum jump of about 0.133 m obtained during 2000–2005 over 1995–2000 was the highest since systematic cultivation of apple started in Himachal Pradesh during 1965–1970 (Fig. 9.1).

The production continued to grow positively. It was 41.44 thousand t in 1965–1970 and rose to 406.76 thousand t in 2005–2007. The area during the above period increased from 17.8 to 90.2 thousand hectares. Precisely saying, there was an increase of about 10 times in apple production and of about 5 times in area under cultivation. Apple cultivation experienced a "sluggish growth phase" or even negative growth in fruit production during 1990–2000. Climate studies have indicated that the decade was the hottest of the century. Hence, it could be inferred that apple cultivation may experience adverse growth in some regions due to negative influences of global warming on the regional climate. This negative effect may enhance unless appropriate mitigation and adaptation measure are put in place, in time.

9.2.2 Apple Productivity

Apple productivity achieved on 5-year basis, since 1965–1970 was maximum, i.e., 4.89 t ha^{-1} achieved during 1985–1990 and declined to 2.99 t ha^{-1}during 1995–2000. Later, during 2000–2005, productivity regained upward trend showing its value of 4.39 t ha^{-1} (Fig. 9.2). During 2005–2007, productivity was 4.51 t ha^{-1}. However, it is much less than the well-managed apple orchards with average productivity of 8–9 t ha^{-1} in Shimla.

9.3 Past and Current Climate

Rising global temperature has triggered large-scale changes in the energy exchange processes (radiative forcings) affecting the atmospheric circulation and precipitation patterns (Fallot et al. 1997; Zhai et al. 1999; Beniston 2003). The studies in Nepal Himalaya (Shreshtha et al. 2000) and upper Indus basin in the North-western Himalaya (Archer and Fowler 2004) have shown minor and statistically nonsignificant variations in the precipitation in the last century. The ecosystems which are most vulnerable to the specter of climate change are high mountain areas such as the Alps, the Rockies, the Andes, and the Himalayas (Beniston 2003).

9.3.1 Short-Term Trends in Temperature and Precipitation

Mean maximum temperature at Shimla showed a consistent increasing trend from 1976–1980 to 2006–2007. The period between 1996 and 2005

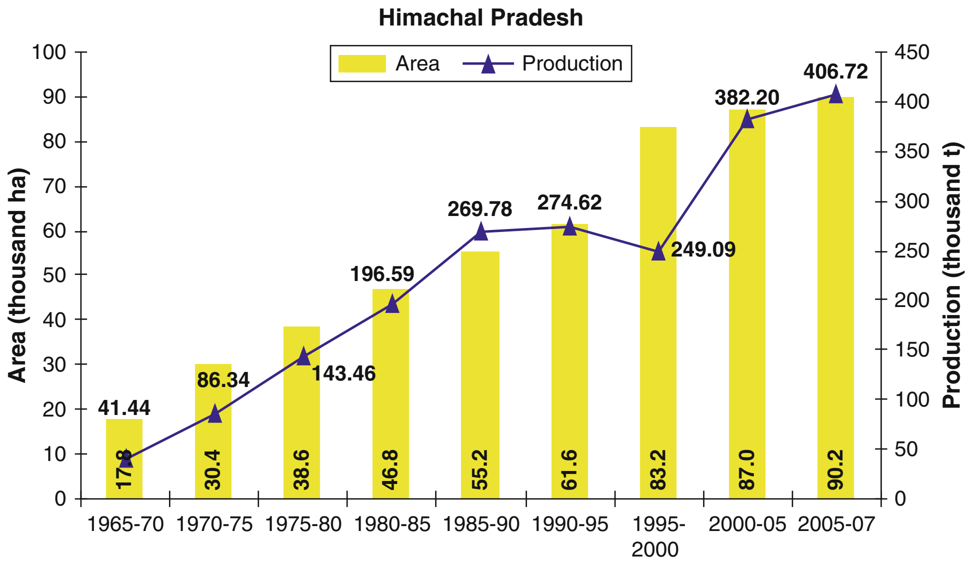

Fig. 9.1 Land area under apple and production trends in Himachal Pradesh

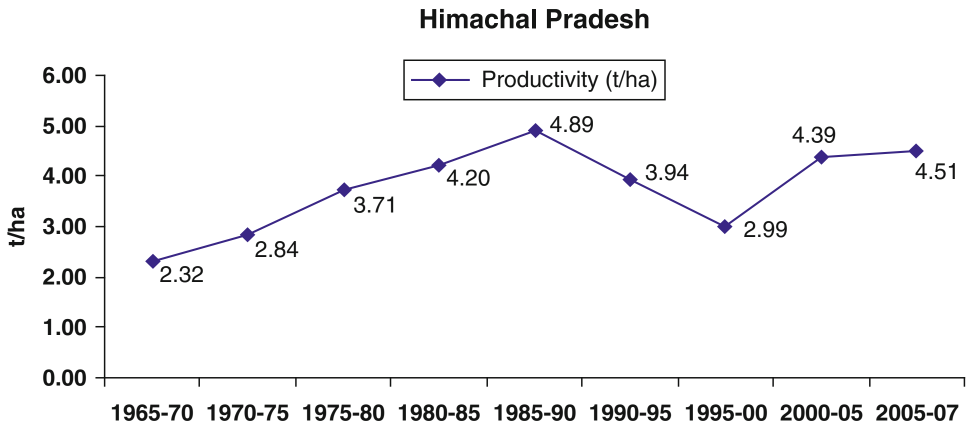

Fig. 9.2 Apple productivity trends in Himachal Pradesh

remained hottest in the region, and an increase of 2.53°C during 2001–2005 over 1976–1980 was observed.

Variations in rainfall as well as snowfall followed a negative trend. At Shimla total rainfall during 1973–1975 was 1346.93 mm which decreased to a level of 816.15 mm during 2006–2007. From 1996 to 2000 onward, rainfall decreased by about 17 % until 2006–2007.

The region received 190.53 cm of total snowfall during 1973–1975 which increased to 827.38 cm during 1981–1985. Later on, it declined drastically to a level of 101.90 cm during 1986–1990, and since then it has leveled off touching the lowest value of 78 cm in 2006–2007. The reason for decline in snowfall may be due to increase in temperature especially minimum temperature.

Variations in temperature and precipitation were also analyzed season wise, i.e., summer (June, July, August), autumn (September, October, November), winter (December, January, February), and spring (March, April, May). The meteorological

Table 9.3 Increasing winter temperature at different stations in Northwestern Himalaya

Station	Time period	Mean max.	Mean min.	Av. winter	Remarks
Shimla	1901–2002	2.6	1.0	1.80	Bhutiyani et al. 2007
	1991–2000[a]	1.83	−0.14	0.89	–
	2001–2007[a]	3.42	0.74	2.80	–
Solan	1991–2000[a]	0.99	−0.08	0.45	–
	2001–2007[a]	2.84	−1.12	1.98	–
Srinagar	1901–2002	1.1	1.2	1.1	Bhutiyani et al. 2007
Leh	1901–2002	1.3	0.4	0.85	-do-
(N.W. Himalaya)[b]	1901–2002	1.7	1.7	1.7	-do-

[a] Increase in temperature relative to baseline of 1972–1990
[b] Average annual: 1.6°C

data w.e.f. 1973–1990 was taken as baseline. Winter temperature showed highest increase in maximum temperature. It was 3.42°C during 2001–2007 over the baseline period of 1973–1990. An increase of 0.97°C was recorded in minimum temperature during the same period which was highest among all the seasons.

Total rainfall at Shimla has decreased over the years in each season except winter wherein small increase in total rainfall occurred over the baseline during 1991–2000 as well as in 2001–2007. Maximum reduction in total rainfall, 196.18 mm, was recorded in summer season during 2001–2007 over baseline. Wet temperate hills of Shimla have experienced drastic reduction in snowfall. In the baseline period, the region used to receive snow during November, i.e., early winter season. It has now been pushed to January and February months.

9.3.2 Long-Term Trends in Temperature and Precipitation

Long-term trends in maximum, minimum, and mean annual air temperatures across the Northwestern Himalayas (NWH) during the twentieth century have revealed a significant and faster rise in warm winters (Bhutiyani et al. 2007). High-resolution ice core data obtained from Tibet confirm the twentieth century rise in air temperature. It is attributed to the anthropogenic activity in India and Nepal, which is reflected in doubling of chloride and a fourfold increase in dust concentration in the ice cores (Liu and Chen 2000; Thompson et al. 2000).

For the Northwestern Himalaya as a whole, the annual warming rate for the last century is estimated to be about 1.6°C, but warming in winter is higher (1.7°C). Among the three locations, Shimla, Srinagar, and Leh, Shimla became the warmest (1.8°C) and Leh (0.85°C) the least. Mean maximum temperature increase at Shimla was exactly double to that of Leh (1.3°C) and slightly more than the double to that of Srinagar. The extremely high increase in mean maximum temperature during winters (3.42°C) at Shimla during the current decade (2001–2007) which is almost double to the NWH winter season average on century scale is indicative of the increasing winter warming in this region (Table 9.3).

The total annual and monsoon precipitation variations in the Northwestern Himalaya (Bhutiyani et al. 2009) for the period 1866–2006 have shown decreasing and significant trend. In contrast, the winter precipitation has shown increasing but insignificant trend. Contrary to the global estimate of increasing precipitation made by certain models (IPCC 2001; Kripalani et al. 2001), majority of the studies on long-term variation in Indian Summer Monsoon rainfall (ISMR) have shown decreasing but insignificant trend over the Indian subcontinent (Thapliyal and Kulshrestha 1991; Srivastava et al. 1992; Ahmed et al. 1996; Pant and Rupa Kumar 1997). An overall decreasing trend in both depressions and cyclonic systems after the middle century may have been partly responsible for such behavior (BhaskarRao et al. 2001; Singh 2001).

Table 9.4 District-wise winter (November–February) temperature trends in Himachal Pradesh for mid-period (2021–2050) based on HadRM3 model scenario AIB

	T_{max}(°C)	$T_{min.}$(°C)	Average(°C)
I) Subtropical–subtemperate region			
Bilaspur and Hamirpur	1.84	2.45	2.14
	(1.98)	(2.20)	(2.09)
Solan and Sirmaur	1.64	2.19	1.91
	(1.77)	(2.04)	(1.90)
Una	1.34	2.36	1.85
	(1.45)	(2.07)	(1.76)
Mandi	2.19	2.79	2.49
	(2.34)	(2.18)	(2.26)
Kangra	1.71	2.36	2.03
	(1.79)	(2.19)	(1.99)
Average temperature	*1.74*	*2.43*	*2.08*
	(1.87)	*(2.14)*	*(2.00)*
ii) Subtemperate–temperate region			
Shimla	2.51	2.54	2.52
	(2.75)	(2.38)	(2.56)
Kullu	2.04	2.78	2.41
	(1.85)	(2.53)	(2.19)
Lahaul and Spiti	2.24	2.82	2.53
	(2.14)	(2.50)	(2.32)
Kinnaur	2.06	2.71	2.38
	(1.91)	(2.53)	(2.22)
Chamba	2.00	2.99	2.49
	(1.98)	(2.37)	(2.17)
Average temperature	*2.17*	*2.77*	*2.47*
	(2.13)	*(2.46)*	*(2.29)*

Figures in brackets are average values of Dec–Feb months, only

9.4 Probable Impacts of Climate Change Scenario A1B on Horticulture in Medium-Term (2050) Period

Overall scenario of the state for mid-period (2021–2050) (Table 9.4) has revealed that average increase in mean minimum and mean maximum temperature during winter in subtropical–subtemperate climatic conditions will be by 2.43°C and 1.74°C with a seasonal average of 2.08°C. Similarly, in subtemperate–temperate climatic conditions, the respective increase will be by 2.77°C and 2.17°C with a seasonal average of 2.47°C. Thus, it is predicted that increase in winter temperature will be higher in temperate, i.e., middle Himalaya than subtropical, i.e., Shiwaliks and outer Himalayas.

The state of Himachal Pradesh represents mainly two broad groups of climatic conditions favoring subtropical as well as temperate horticultural crops. The likely impacts of climate change in the districts falling in subtropical–subtemperate zone as well as sub-temperate–temperate zone have been described as below.

9.4.1 Subtropical–Subtemperate

These climatic conditions are prevalent in the districts of Bilaspur, Hamirpur, Una, Kangra, Solan, Sirmaur, and Mandi covering their area either wholly or partly. Future trends in terms of rainfall have revealed almost negative trends during the period January–June barring February and May in all these districts (Figs. 9.3 and 9.4). However, Solan and Sirmaur districts will receive decreased rainfall during all the months beginning from January to June (Fig. 9.3). About half of the geographical area of these two districts represents subtemperate climate which suits for the cultivation of off-season vegetable crops besides stone fruits like peach, plum, and apricot. Reduction in rainfall during January–June will influence the production of these crops, adversely.

In the remaining districts, the production of winter crops and subtropical fruits like mango will also suffer from water stress. However, increased monsoon rainfall (July–August) as well as the autumn (September–October) and early winter (December–January) will favor good harvest of kharif crops besides adequate water for recharging different aquifer systems. This will also improve the groundwater hydrology of the region.

Mean maximum and minimum temperature will increase, but increase in mean minimum will be more in comparison to mean maximum in all the districts except Una district where summer months will experience more rise in maximum temperature (Figs. 9.5, 9.6, 9.7, and 9.8). These climatic conditions may cause frequent "heat wave" events in this district.

Higher increase in mean minimum temperature than mean maximum will make the region less

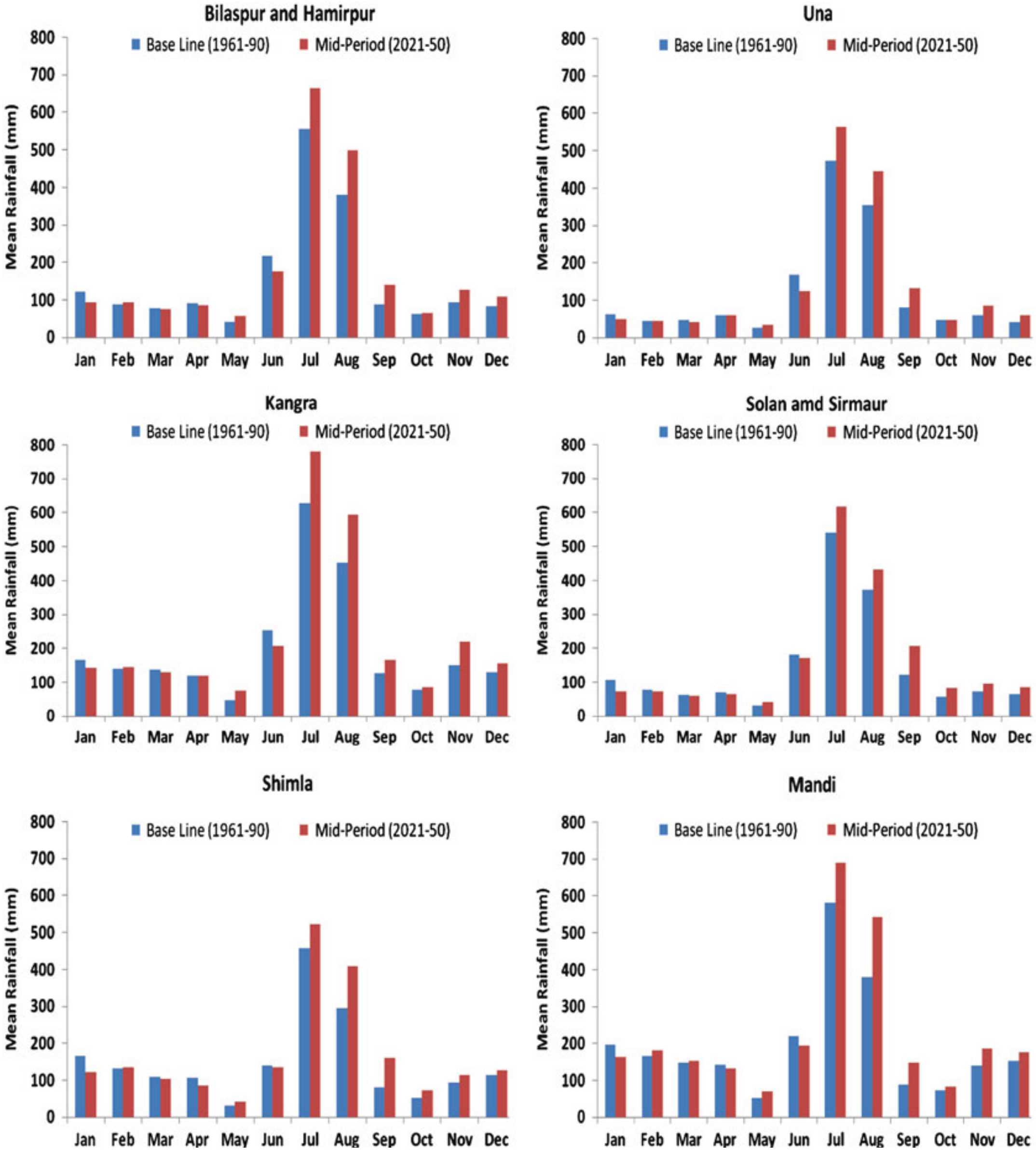

Fig. 9.3 District-wise mean monthly rainfall for baseline and mid-period under A1B climate scenario

prone to frost. There will be a reduction in frost events. The impact of frost or cold injury will be further reduced by enhanced precipitation during October, November, and December. Farmers may enjoy good harvests from subtropical fruits like mango.

Increased monsoon, autumn, and early winter rainfall will also enhance the opportunities for water harvesting and storage.

9.4.2 Subtemperate–Temperate

The region covers the areas of Shimla, Kullu, Mandi, Chamba, Kinnaur, and Lahaul–Spiti districts. Month-wise rainfall pattern revealed increased trend during July to December in Shimla, Mandi, and Kullu districts. However, during the period January–June, Shimla will experience less rainfall. Mandi and Kullu on

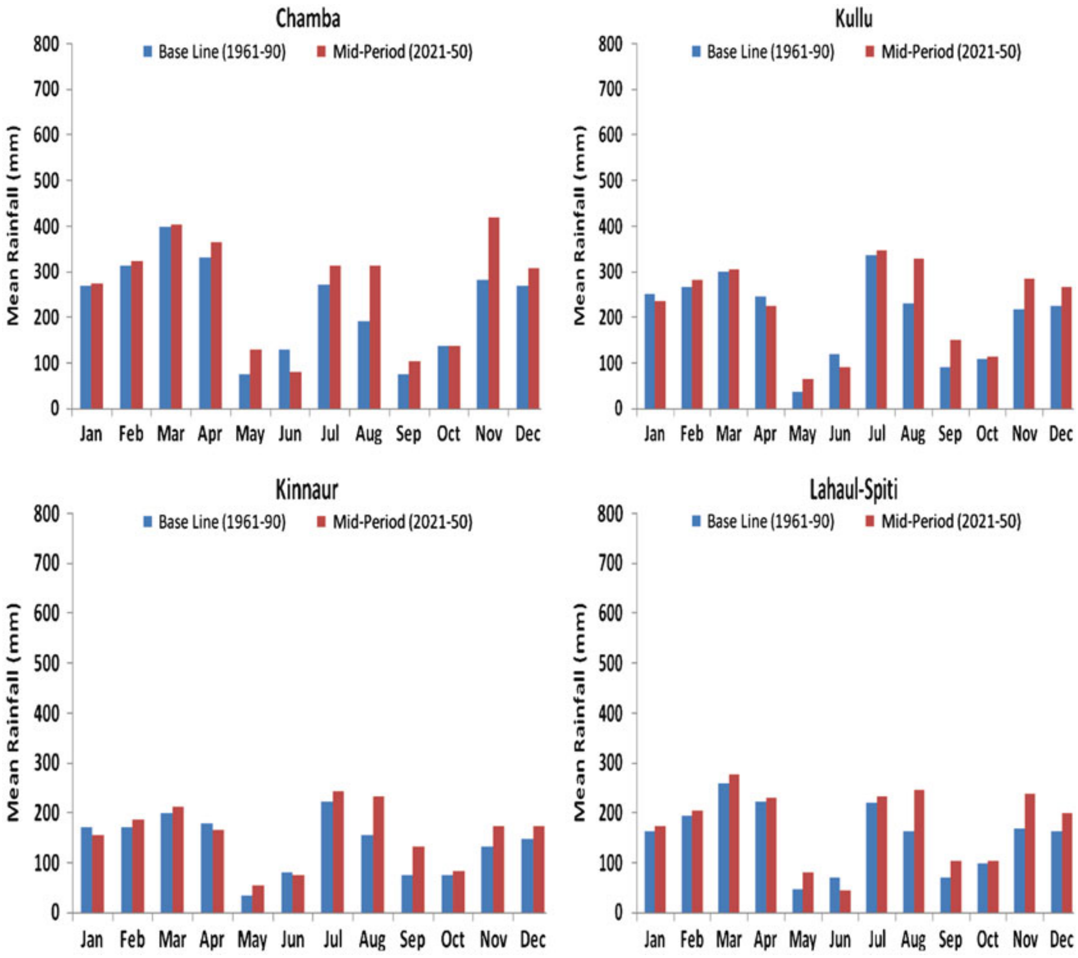

Fig. 9.4 District-wise mean monthly rainfall for baseline and mid-period under A1B climate scenario

the other hand will be compensated with slight increase in rains during February, March, and May. Chamba, Kinnaur, and Lahaul–Spiti will be benefitted by increased rainfall during each month of the year.

Due to the increase in both maximum (2.00–2.50°C) and minimum (2.54–2.99°C) winter temperatures in all the districts of temperate region coupled with the rainfall pattern, temperate fruit production will have following impacts:

- District Shimla owing to increased temperature and less rainfall during January–June will experience
  - Reduced chill accumulation units.
  - Reduced soil moisture availability and increased evapotranspiration resulting in more water stress conditions.
  - Reduced snowfall and faster melting will aggravate water deficit conditions.
  - Enhanced temperature during February–March may induce early flowering and better fruit set in apple resulting in higher yields, if fruit trees are not constrained with moisture stress.
  - Moisture conditions, however, will have an adverse effect on flower and fruit drop, increased insect–pests infestation especially at elevations around 1800–2000 m.asl.
- Kullu and Chamba will experience almost similar adverse influences as Shimla. But due

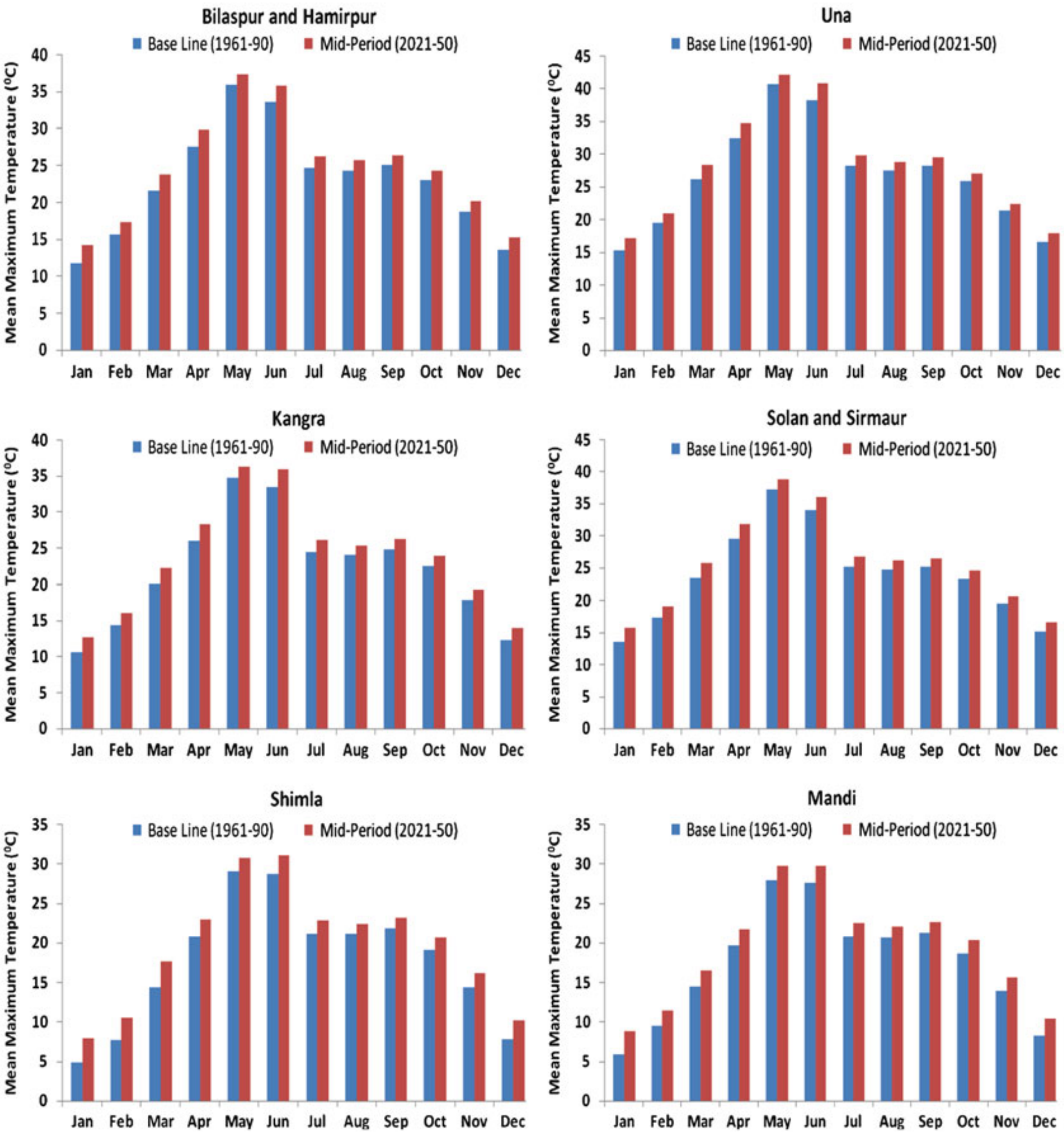

Fig. 9.5 District-wise mean maximum temperature for baseline and mid-period under A1B climate scenario

to increased rainfall in each month barring June, fruit growers in this district will harvest comparatively better crop yields.

- Climate conditions in Kinnaur reveal that fruit production in low and mid altitudes may suffer adversely, but at higher altitudes, production is very likely to increase.

Contrary to above, in district Lahaul–Spiti due to increased rainfall every month and also increase in temperature during every season, more congenial climatic conditions will be created for better plant growth and yield. It will open up opportunities for cultivation of new crops and fruits besides existing vegetables and cereals in the region.

9.4.3 Impact on Chilling Hours Accumulation

Data presented in the Table 9.5 revealed that the actual mean temperature of three winter months

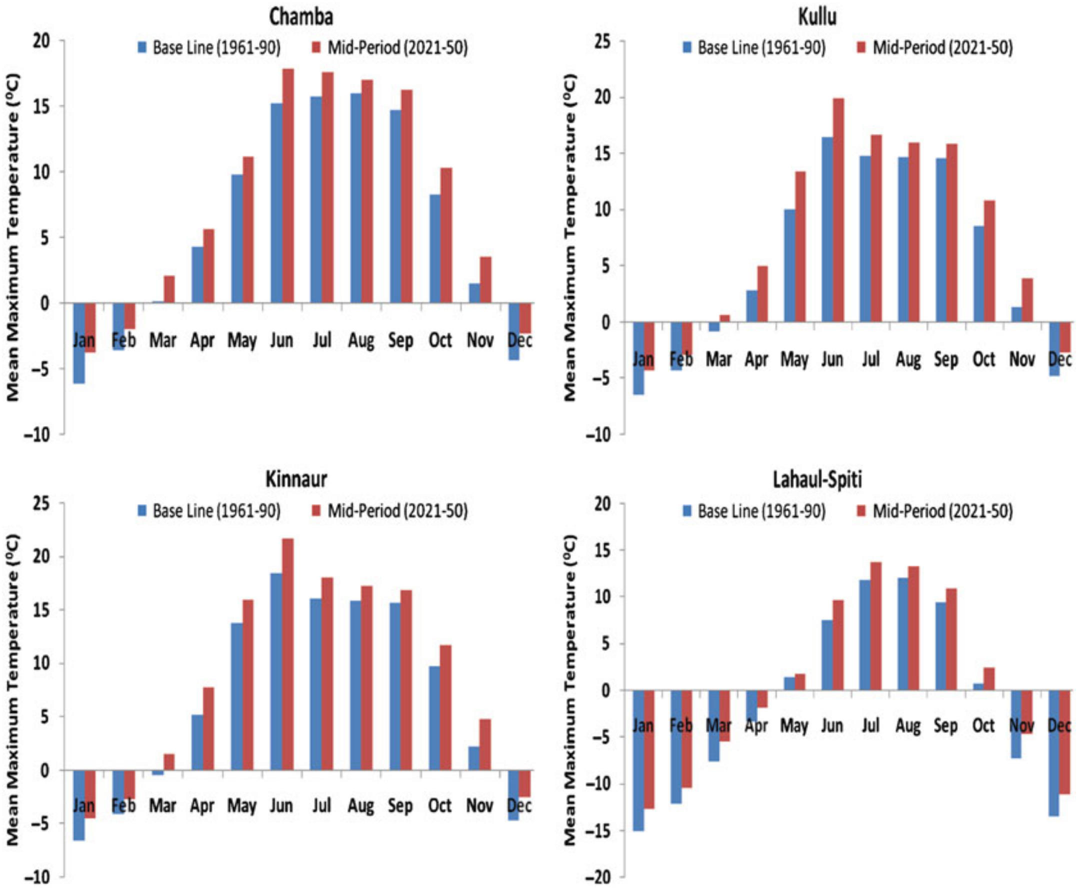

Fig. 9.6 District-wise mean maximum temperature for baseline and mid-period under A1B climate scenario

(December, January, and February) for the period 1960–1990 was 6.1°C. The corresponding chilling hours calculated on the basis of regression equations were 1,217 (0–7.2°C) and 1,374 (< 7.2°C). The regression equations were derived from the actual chilling hours experienced during the period 1994–1995 to 2009–2010. According to scenario AIB, the mean temperature of 3 months for the period 1960–1990 was 0.9°C, and the corresponding chilling hours were very high. In the projected mid-period (2021–2050), the mean temperature is 3.4°C, and the corresponding chilling hours are 1,614 (0–7.2°C) and 1,876 (<7.2°C). The data further revealed that mean temperature by 2021–2050 will rise by 2.5°C over the baseline.

The projected impact of the increased mean temperature over the actual temperature of 6.1°C will be as follows.

Base mean temperature of 6.1°C corresponded to 1,217 h (0–7.2°C) and 1,374 (<7.2°C) chilling hours. The projected increase of 2.5°C over the base temperature will make it 8.6°C. This will reduce the chilling hours to 849 (0–7.2°C) and 909 (<7.2°C) (Table 9.6). Further, if the mean temperature increases above 10.6°C, then in such areas chilling hour accumulations will be impacted badly.

Chilling requirements of some of the important apple cultivars are presented in Table 9.7. Most of the common cultivars have medium range of chilling requirement, i.e., 600–800 h (0–7.2°C) and 651–1,050 h (< 7.2°C). However,

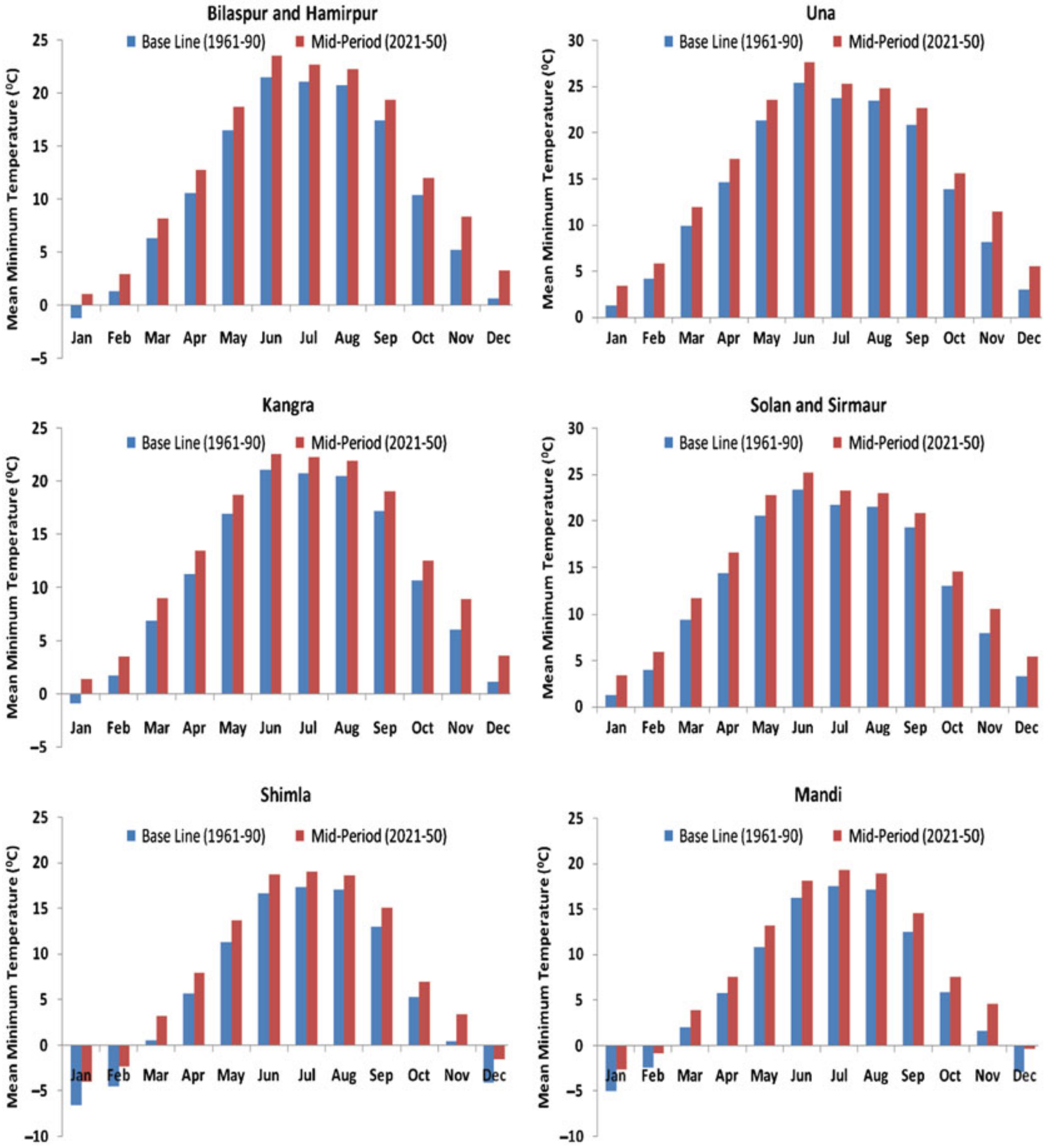

Fig. 9.7 District-wise mean minimum temperature for baseline and mid-period under A1B climate scenario

the cultivars such as Fuji, Gala, Braeburn, and Granny Smith have low to medium chilling requirement based on <7.2°C temperature.

It is, therefore, inferred that chilling hour accumulation will decrease with the increase in mean minimum temperature to 8.6°C. But most of the apple cultivars will be able to fulfill their chilling needs owing to their optimum chilling hour requirement limits. But an increase in temperature to 10.6°C will reduce the chilling to 555 h (0–7.2°C), and under such situation, the chilling will be a limiting factor for apple cultivation especially cultivars with medium to high chilling requirements.

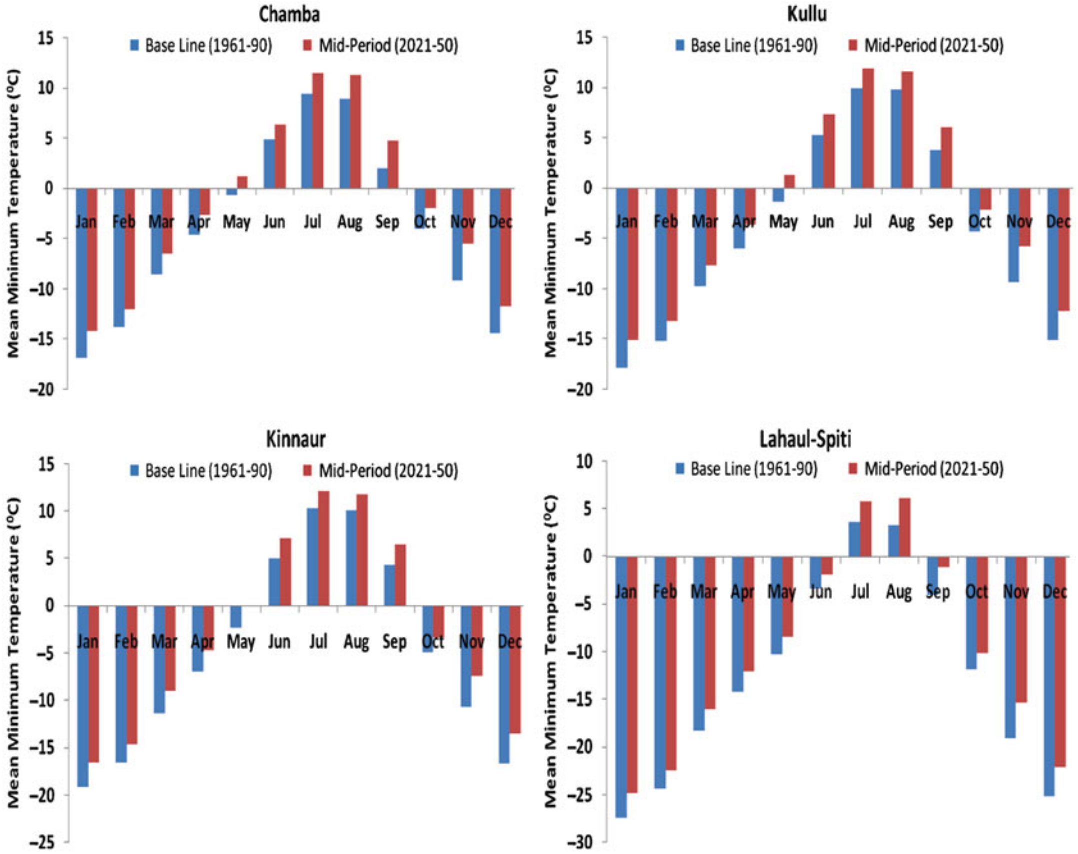

Fig. 9.8 District-wise mean minimum temperature for baseline and mid-period under A1B climate scenario

Table 9.5 Mean temperatures and corresponding chilling hours accumulation based on the actual data as well as data from HadRM3 model scenario AIB for wet temperate region of Himachal Pradesh

Actual recorded			HadRM3 model scenario AIB					
1960–1990			1960–1990	2021–2050				
Tmean (°C)	Chilling hours		Tmean (°C)	Chilling hours		Tmean (°C)	Chilling hours	
	0–7.2°C	<7.2°C		0–7.2°C	<7.2°C		0–7.2°C	<7.2°C
6.1	1217	1374	0.9	1981	2340	3.4	1614	1876

Chilling hours of the three periods were calculated on the basis of mean temperatures of winter months (DJF) using the following equations:

1) Chilling hours (0–7.2°C) $Y = -147.08X + 2113.7$ ($R^2 = 82\%$)
2) Chilling hours (>7.2°C) $Y = -185.94X + 2508.2$ ($R^2 = 89\%$)

9.5 Strategies for Adaptation for Increased Climatic Risk

1. Strengthening the resilience of communities and ecosystems against climate-related risks
2. Water and soil moisture conservation and livelihood generation to meet the upcoming effects of climate change
3. Enhance, maintain, and conserve soil and plant carbon pool of highly vulnerable mountain slopes
4. Adopt tree-based/mixed farming systems to conserve biodiversity and increase climate resilience of mountain farming systems
5. Barren land use planning of unproductive land of hilly areas by implementing proper framework

Table 9.6 Projected impact of unit increase (0.5°C) over the mean temperature of 6.1°C on chilling hours accumulation

	Chilling hours	
Temp°C	0-7.2°C	<7.2°C
6.6	1143	1281
7.1	1069	1188
7.6	996	1095
8.1	922	1002
8.6	*849*	*909*
9.1	775	82.5
9.6	702	723
10.1	628	630
10.6	555	537
11.1	481	444

Table 9.7 Optimum chilling requirements of some cultivars of apple in Himachal Pradesh

	Chilling hours	
Cultivar	0–7.2°C	<7.2°C*
Delicious	600–800	651^{M}–1050
Golden delicious	600–800	651^{M}–1050
Fuji	600–800	L–M
Gala	600–800	L–M
Jonagold	–	M
Granny Smith	400–600	L–M
Braeburn	–	L–M
Anna	–	L
Rome beauty	800–1100	–

*L = 100–650
M = 651–1050
H => 1050

6. Rescheduling of sowing/planting and crop management practices as per the change in rainfall pattern
7. Greater support for agricultural research and extension to promote sustainable models of rainfed farming
8. Establish climate information management and early warning systems
9. Networking of local research and extension institutions and building local institutional capacities
10. Enhanced afforestation/reforestation activities to increase the forest cover, maintain and conserve the existing forests which directly or indirectly contribute in sustaining the temperate fruit production systems
11. Maintaining and conserving the flow of major river systems as well as their tributaries by stopping avoidable industrial growth in their catchments
12. Creation of “Adaptation Fund” and provide compensation to the right holders and communities who adopt measures to reduce GHG emissions and conserve the Himalayan ecosystems
13. Monitoring and surveillance of climate factors and providing early warning.

9.6 Future Research Needs

- Site-specific adoption packages for technologies to current climatic risks
- Development of stress resistant horticulture crop varieties
- Studies on the role of forests especially conifers in maintaining the temperate production systems
- To explore the contributions of traditional knowledge to climate research
- Use of efficient irrigation systems
- Integrated pest management
- Strengthening extension services
- Recording of meteorological and hydrological data in inaccessible regions of Northwestern Himalayas
- Overall regulatory framework pertaining to land use, groundwater, forestry resources, and other natural resources on which livelihood of hill people depend.

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Development of Vegetable Hybrids for Climate Change Scenarios

10

Arvind Kapur

Abstract

Vegetables are grown in diverse climatic conditions from temperate regions to extreme tropics. In tropics and subtropics, the climate shifts are more prominent, and major vegetables are grown round the year in these areas. Breeding vegetable crops suitable for different agroclimatic conditions is the key objective of the commercial companies. Many hybrids are already released by private companies which are adaptable under different agroclimatic conditions. Different breeding options are discussed to meet the challenges of climate change.

More than 100 genera are grown globally as fresh vegetables, but 35–40 genera are the important vegetables which are grown in major vegetable growing areas of the world. Presently, global vegetable seed business is worth US$ 8.0 billion out of US$ 42 billion total seed industry (Fig 10.1). In the last 40 years, it has grown significantly from US$ 0.8 billion to US$8.0 billion, by almost 10 times (Fig 10.2). This clearly indicates the importance of vegetables in food, health and nutrition globally. The Asian vegetable industry is also growing, and traded seed market of vegetable seed is touching $3 billion, and China is the largest partner with $1.5 billion (excluding potato and garlic) (Fig 10.3). The ever expanding area as depicted by the seed sales is indicating that the new varieties are significantly contributing towards higher productivity and value addition thru taste, flavour and higher shelf life.

10.1 Introduction

Globally, tomato is the biggest crop and occupies 11% of the total vegetable seed market. The crops like cabbage, sweet pepper and lettuce occupy about 7% each of the market. The watermelons, onions, melons, Chinese cabbage and hot peppers occupy around 5% of the total vegetable seed market (Fig. 10.4). As the second

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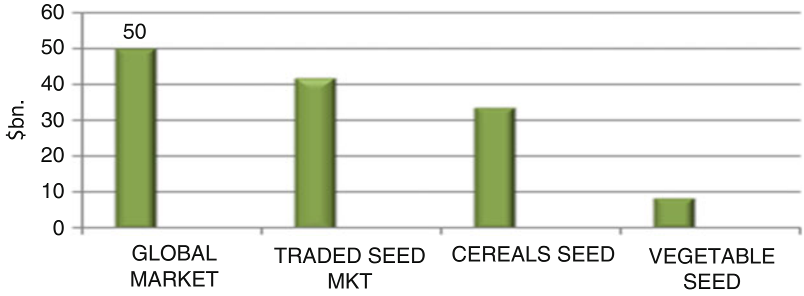


Fig. 10.1 Global seed market and seed market of crops

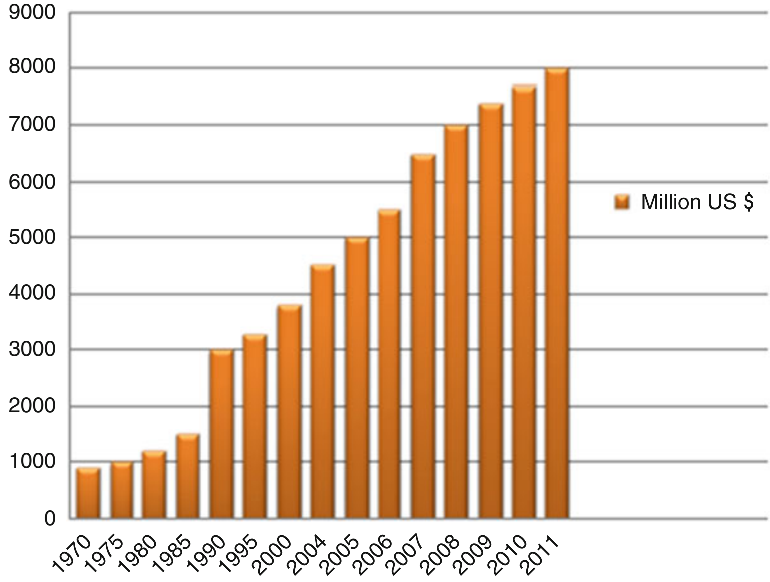


Fig. 10.2 Growth of vegetable industry in last four decade

largest producer of fruit and vegetable in the world after China, India produces a wide variety of vegetables. As per the National Horticulture Board information of 2010 published by National Horticulture Board, India produced 71.50 million ton of fruits and 134 million ton of vegetables during 2009–2010. The area under cultivation of fruits stood at 6.4 million ha, while vegetables were cultivated at 8.0 million ha (www.apeda.gov.in).

India is the largest producer of ginger and okra amongst vegetables and ranks second in production of potatoes (10%), onions, cauliflowers, eggplant, cabbages, etc. The vast production base of fresh vegetables offers India tremendous opportunities for export. During 2010–2011, India exported fresh fruits and vegetables worth Rs. 38.56 billion which comprised of fruits worth Rs. 26.35 billion and vegetables worth Rs. 12.21 billion. Mangoes, walnuts, grapes, bananas and pomegranates account for larger portion of fruits exported from the country, while onions, okra, bitter gourd, green chillies, mushrooms and potatoes contribute largely to the vegetable export basket. The major destinations for Indian fruits and vegetables are Bangladesh, UAE, Malaysia, Sri Lanka, UK, Nepal, Saudi Arabia, Pakistan and Indonesia (www.apeda.gov.in).

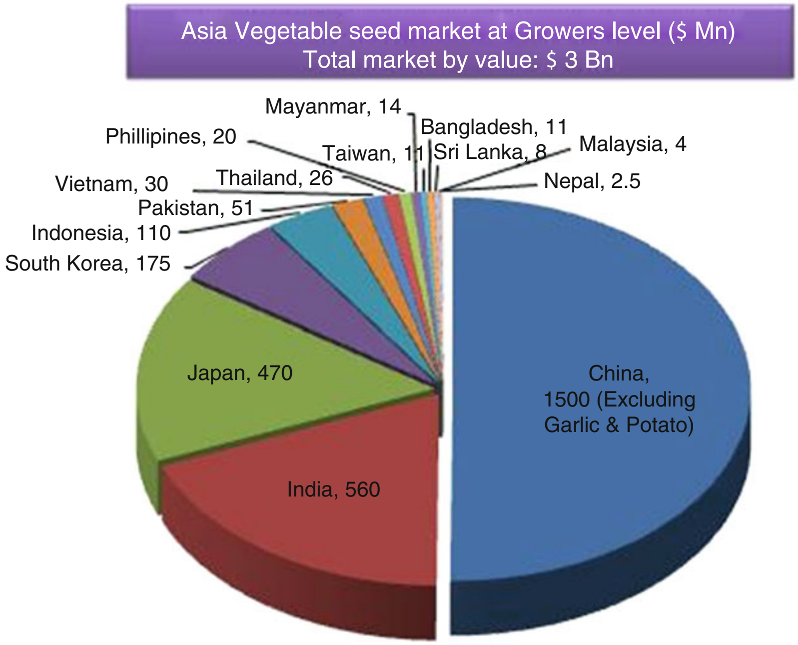


Fig. 10.3 Vegetable seed market of Asia

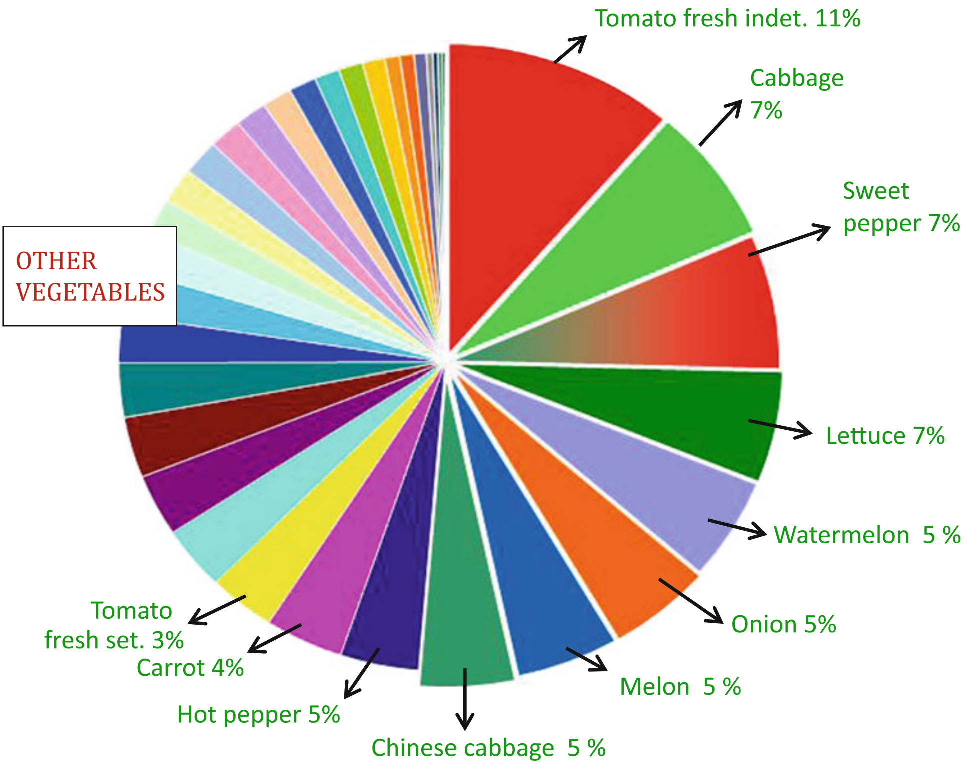


Fig. 10.4 Crop wise segmentation of vegetable crops

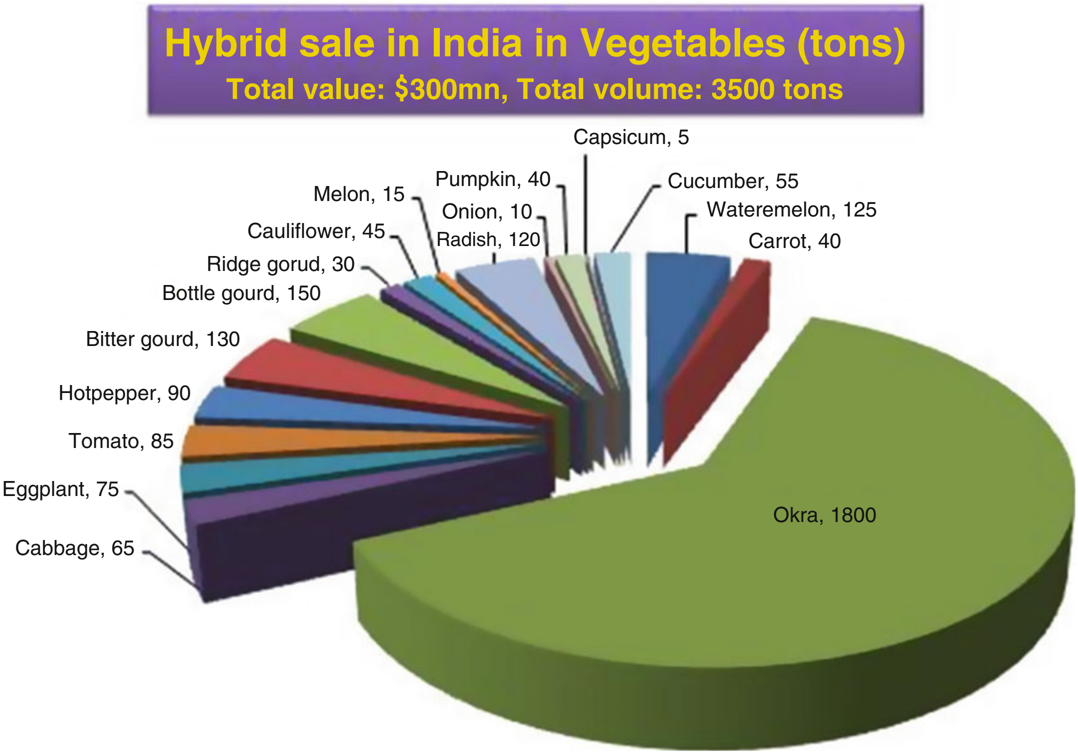


Fig. 10.5 Hybrid vegetable seed sale in India

Total traded seed industry in India is worth US$ 2.3 billion, out of which vegetable accounts for US$ 560 million. Varieties of vegetable crops are grown in India based on the local tastes and recipes. At present, about $260mn of the value of seed come from open pollinated varieties particularly bulk crops like peas, beans, coriander and radish. and $300mn comes from hybrids. In hybrids, by value, tomato, hot peppers and okra have 18% market share each, while cabbage, cucumber and watermelons have 5–7% market share each. Total hybrid seed market is more than $300 million, and more than 3,500 Mt seed is being produced to have overall more than 50% seed replacement rate in hybrid vegetables (Fig. 10.5).

Open pollinated varieties (OPV) vegetable seeds are sold in big quantities in many crops. Still, OPVs of Okra, tomato and hot pepper are being sold in many markets because of local market needs and tastes required for local recipes. Presently, around 40,000 ton seeds of OPVs in around 25 vegetable crops are being sold with a total value of more than $ 260 million. Out of the total OPVs sold in India, 70% is made of beans, coriander, onion and peas by value. The private seed industry is continuously improving the OP varieties and introducing high-performing research varieties. Many of these varieties are also showing intermediary resistance to diseases. In vegetables, even in OPVs, the seed replacement rate is very high, and farmers buy fresh seed every season/year (Fig. 10.6).

10.2 Climate Change and Its Impacts

With the increasing population which is presently at 7.0 billion, the pressure on land is impacting the climate. The greenhouse gases

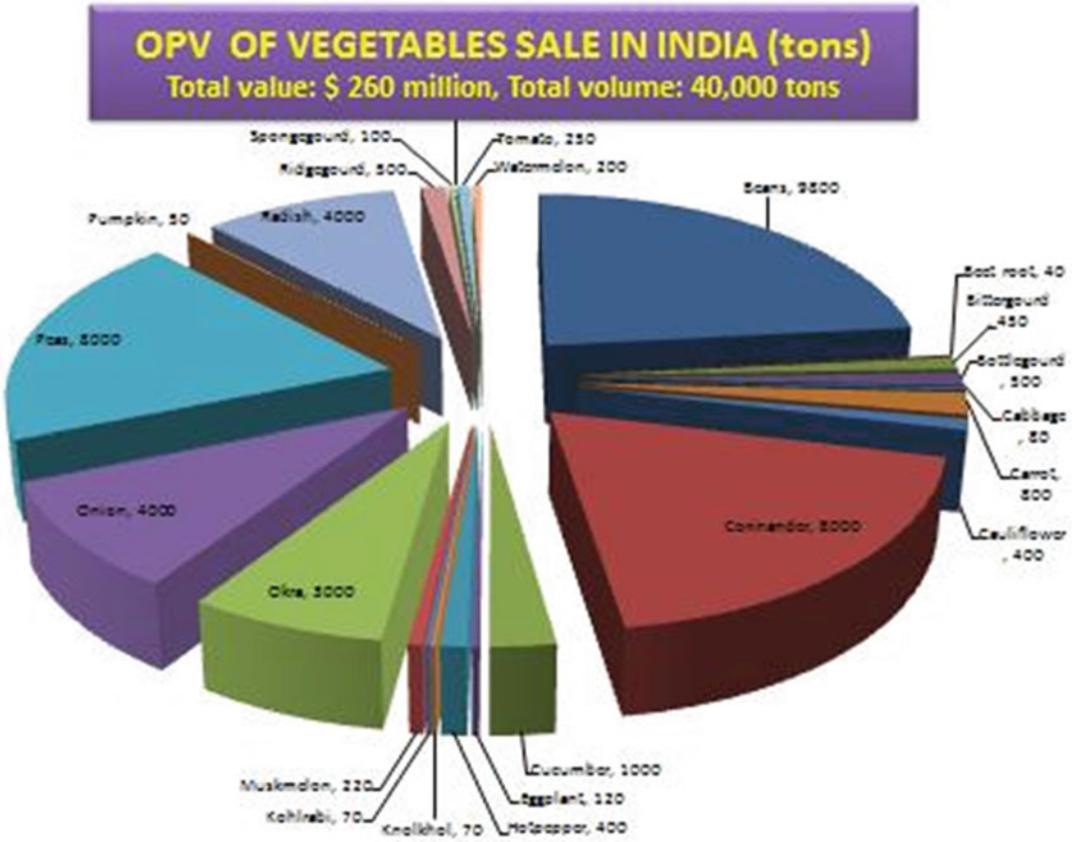


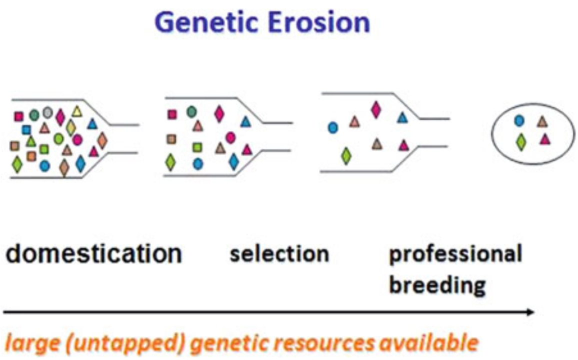
Fig. 10.6 Open pollinated vegetable varieties sale in India

emissions due to human activities are the biggest concern for the climatologists. The rise in temperature and other related changes like increase in sea level, more rains or drought will impact all the living things on the earth. Agriculture which is sensitive to the climate changes will react sharply to these changes. The cropping pattern change and the change in planting seasons will put pressure on the breeders to develop adaptable hybrids for these conditions. With the changing climatic conditions, the host pathogen interactions will also change. It was observed that more virulent pathotypes are emerging and affecting the crops. The continuous struggle of developing resistance in vegetable crops is a biggest challenge for breeders under these conditions.

10.3 Breeding for Abiotic Stresses

The abiotic stresses like temperature, drought, salinity and floods are the consequences of changing climatic conditions. The breeding for resistance to these stresses is going on presently in many crops. Crops like tomato and hot peppers are bred to grow under high and low temperature without losing the ability to yield as much as in the normal conditions. Similarly, now many drought genes have been identified and being inserted into these crops to develop proof of concept in conserving and utilising the available moisture. These products will help in providing yield stability in areas with limited water supply. Similarly, many tomato lines are under development which can tolerate high level of salinity.

Fig. 10.7 Loss of important genes during domestication



Abiotic stresses are the complex traits and need further research before these can be commercially exploited.

10.4 Breeding for Disease Resistance Under Changing Climate

Most of the vegetables in tropics and subtropics are susceptible to many diseases. There are heavy losses of yield and quality due to disease infestation and chemical sprays. Heavy use of chemicals to control these diseases caused contamination of soil, water and atmosphere. These are also causing problems to human health and animals. Excessive use of chemicals have led to development of resistances in many pathogens. The acceptance of organic food is also pushing breeders to develop resistant varieties.

10.4.1 Losses due to Diseases Vegetables

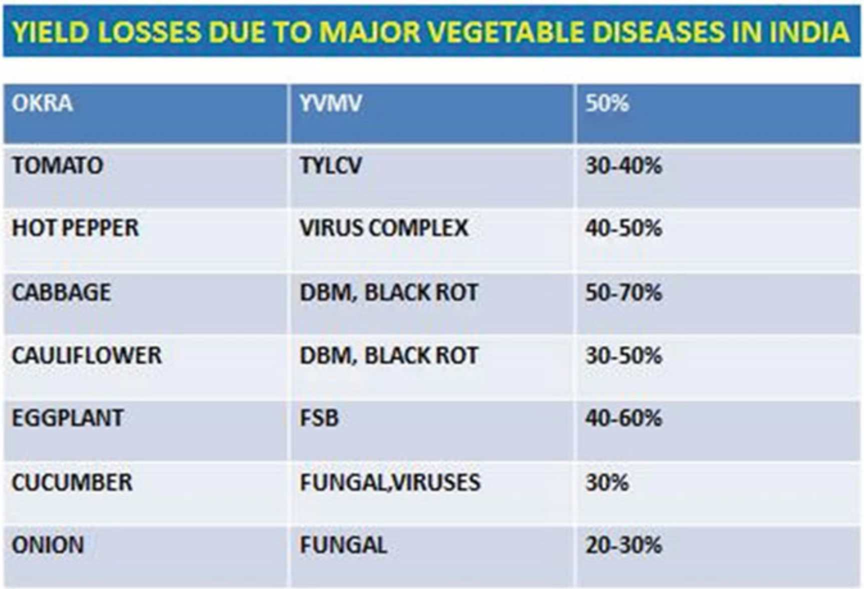
Around 35–40% loss of vegetable production happened every year globally. There are about 100,000 microbial/fungal pathogens, 10,000 insect pathogens and 30,000 weeds causing extensive damage to vegetable crops. Worldwide, 20,000 pesticide formulations are being used to control pests, and out of which 1,600 are commonly used formulations. It is estimated that almost 3 million tons of chemicals is consumed in vegetable growing globally. In India, almost 1.40 lakh t of pesticides are consumed in vegetable growing. The pre-harvest losses in vegetables in India are 10.5% (Betne 2011).

10.4.2 Breeding Approaches for Disease Resistance

Various approaches have to be deployed to impart disease resistance to different vegetable crops. These include conventional approaches through wide hybridisation with high selection pressure. The use of MAS and MAB is going to be an efficient tool to breed for resistance development in elite material. The introgression of resistant genes, isolated from same or different species through genetic modification, is an important, specific and efficient tool. All these approaches are required to achieve the durable resistance to the developed and cultivated varieties. During domestication of these crop plants, we have lost many important genes which we have to recapture under existing selection pressure (Fig. 10.7).

10.4.2.1 Breeding for Multiple Resistance in Hybrids

Most of the vegetable crops are infested by multiple diseases including fungal, bacterial, viruses and insects. Most of the diseases are in epidemic form and multiple resistances have to be incorporated for the better performance of hybrids. Major crops like tomatoes and hot peppers are suffering from multiple diseases, and developing resistance



YIELD LOSSES DUE TO MAJOR VEGETABLE DISEASES IN INDIA

OKRA	YVMV	50%
TOMATO	TYLCV	30-40%
HOT PEPPER	VIRUS COMPLEX	40-50%
CABBAGE	DBM, BLACK ROT	50-70%
CAULIFLOWER	DBM, BLACK ROT	30-50%
EGGPLANT	FSB	40-60%
CUCUMBER	FUNGAL,VIRUSES	30%
ONION	FUNGAL	20-30%

Fig. 10.8 Yield losses due to diseases in vegetables

to all these diseases is a herculean task by using conventional breeding techniques. The yield losses are heavy due to these diseases.

Pre-harvest losses due to these diseases are significantly high (Fig. 10.8). In tomato and hot pepper, the losses due to viruses is as high as 50%, while diamond back moth (DBM) and black rot caused up to 70% losses in the crop at pre-harvest level.

10.4.2.2 Problem of Pesticide Resistance and Pesticide Residue

Worldwide, around 500 insect-pests, mites and spiders have developed pesticide resistance including 31 in India. Diamond back moth (DBM) has also developed resistance to many pesticides. Similarly, fruit and shoot borer of eggplant, many mites and thrips have developed resistance to available pesticides. The origin of new races in fungal diseases and new strains of bacteria is the other challenge with pesticides and breeding companies. The other issue is of pesticide residue. Since many vegetable crops are eaten raw as salads, these residues cause lot of health risks. Many organisations have evaluated the residue level from fresh vegetables, and more than 60% of the samples are showing residues above the permitted limits. All these issues are pointing towards the need of development of resistance through breeding, and only development of resistant varieties can solve some of these issues.

10.5 Sources of Resistance

Conventional breeding coupled with molecular marker assistance is the best choice for breeding for resistance. Many wild species are rich sources of resistance genes in many vegetable crops. For example, in tomato, the genes for TYLCV are derived from *L. pimpinillifolium* while insect resistance from *L. pennellii.* Drought resistance genes are found located in *L. chilense* and *L. pennellii.*

Similarly, bacterial wilt which is caused by *Ralstonia solanacearum* is a major disease in many parts of Asia. The resistance source is found in Hawaii 7,996 accession. For phylotype I strain which is predominantly found in Asia, large BW QTLs are detected on chromosome 12. Multiple BW QTLs are also located on chromosome 6 which are important for resistance to phylotype I and II strains.

It is important to build durable resistance through wide hybridisation and making selection by markers to achieve accumulation of genes for resistance.

Similarly in peppers, many wild relatives have important genes for resistance against fungi and viruses in species like *Capsicum chinense*, *C. baccatum* and *C. frutescens.* We have to reconstruct the genome using the crosses between the cultivated species and these resistant species and bring back certain important genes which we had lost during earlier selection pressure. The new tools of molecular markers and genome sequence will facilitate to create durable resistance against diseases developing under changing climatic conditions.

The host and pathogens are in dynamic equilibrium with each other, and both are evolving and changing under climate shifts. Pyramiding genes and alleles is a continuous process, and this will lead to a durable resistance to the released hybrids.

10.5.1 Marker-Assisted Breeding

The molecular marker tools which are available to the breeders have unprecedented power for selection of the right genotype. With the marking of certain genes within a plant genome, breeder can trace it throughout the plant life cycle. Breeder can determine the trait before the seed actually go to the ground. Now, the genome sequence is happening at a faster pace, and the available data allows breeders to significantly shrink the time line between initial discovery and the commercial introduction of the hybrids. Today, breeders can get the genetic analysis information from just a portion of the seed coat. DNA now is analysed in close to real time. With DNA analysis from the chip of the seed, a breeder can segregate the seed before sowing based on the presence and absence of a trait. This is going to increase the efficiency almost tenfolds, and breeder can bring the commercial products in 3 years rather than waiting for 8–10 years. With the hundreds of datapoints getting available, the breeders have huge information about the genetic constitution of the seed before planting a single seed in the soil. Many vegetable crops genome is sequenced like tomato, cucumber and melon, and a lot of valuable genes are tagged to be used in breeding and development of products. Presently, markers are being used for TYLCV, TSWV, Ph, Cf, Mi genes.

10.5.2 Gene Insertion Technologies

10.5.2.1 Insect-Resistant Traits

Today, insect-resistant cultivars developed by inserting gene from soil bacteria, the Bt gene, has revolutionised the agriculture. The significant reduction in pre-harvest losses due to the resistance and lesser use of pesticides helped the growers significantly. New genes for insect resistances are being identified with new modes of action. Bt genes are introduced in tomato, okra, eggplant, cauliflower and cabbages for the control of lepidopterans insects. The initial results are very encouraging, and vegetable growers are going to be benefitted by these technologies. The Bt eggplants which may be released soon have great advantage for the farmers against fruit and shoot borer, *Leucinodes orbonalis.* Similarly, *Helicoverpa* species which are infesting fruits of okra and tomato are controlled by Bt. insertions. The diamondback moth (DBM) which attacks cole crops particularly Brassicas have shown resistance too many pesticides. The durable resistance source in the germplasm is not available. The only alternative is to look for gene insertion from other species to impart resistance. Bt. genes were introduced in cauliflower and cabbages, and the initial field trials have shown excellent control of DBM and other lepidopterans insects like *Spodeptra*. Now, genes like Chitinase have been identified to control fungi in vegetable crops. For viruses, already coat protein (CP)-mediated resistance has been used in many crops like squash and papaya. The RNAi and miRNA technologies are being used to control particularly Tospoviruses. These technologies will impart durable resistance to these crops. Companies are continuously searching new genes with new modes of action and even new sources of insect toxins.

10.5.2.2 Herbicide-Tolerant Traits

Herbicide-tolerant trait played a significant role in many crops. Presently, 90% of soybeans and 70% of the corn are planted using the herbicide-tolerant trait. With this trait, no-till cultivation is possible which will not only solve the problem of soil structure alterations due to extensive ploughing but also protect the fauna and flora of soil. With the crop residue in the soils, the organic matter is improving, and the natural insect population increase also attracts and improves the bird population. With Monsanto and Dow AgroSciences coming out with new-generation herbicide-tolerant traits which will control broadleaf and grass weeds. Stacking multiple herbicidal genes will provide diversified options for weed control.

10.5.2.3 Nitrogen Use Efficiency Traits

Several seed companies are now developing traits that allow the crop plants to better utilise the available nitrogen. Fertiliser is the key and an expensive input. Lot of nitrogen gets percolated or washed away is not fully utilised by the plants. So any trait which can increase the efficiency of fertiliser uptake will help the growers to reduce the cost of crop production.

10.5.2.4 Yield Potential Traits

Starch biosynthesis plays an important role in plant metabolism. ADP-glucose pyrophosphorylase (ADPGPP) is a critical enzyme for regulating starch biosynthesis in plant tissues. Starch biosynthesis and dry matter accumulation were enhanced in potato tubers of plants transformed with glgC gene from *E. coli* encoding ADPGPP enzyme. The glgC gene has been introduced in rice also, and the yield potential of these lines is being evaluated. In tomato, florigen gene is identified for yield enhancement. A hybrid tomato plant that gives a bumper crop of sweeter tomatoes has been created by scientists, by cross-breeding from two parent plants.

The hybrid produces about 60% more tomatoes than the average tomato plant, and the sugar content of the fruit is also higher than normal. It carries a mutation in a single gene that controls the timing of flower formation.

The discovery could be applied to other valuable food crops such as potatoes, peppers and eggplant, the geneticists hope. The crop-boosting mutation is seen as a potentially valuable tool to increase global food production in the coming decades.

The scientists discovered the critical role of the florigen gene, which promotes flowering, by cross-breeding a collection of 5,000 tomato plants that had been deliberately mutated, each in a different gene. The researchers found that plants carrying one normal and one mutated florigen gene showed remarkable "hybrid vigour," with a significant boost in yield and sweetness.

10.5.2.5 Male Sterility System

The male sterility system which is being used in *Brassica napus* is a really valuable tool in improving the hybridisation in crops where male sterility systems are either not available or not stable or restoration of fertility is an issue. The barnase-barstar system is also being tried in other crops like vegetables to diversify the male sterility sources.

10.6 Future Technologies to Control Biotic Stresses

With the genomic sequences becoming available for many crops, the identification of function of many important genes and their regulation will provide extra tools in the hands of the breeder. Biotic stresses which are controlled by multi and recessive genes are difficult to breed. For this, we need technological interventions. The targeted mutations (TILLING) technology will also help in generating new gene pool with resistant genes. The evolving pathogens will continuously throw challenges for the breeders in the changing climatic conditions, and breeders have to evolve the host to counter the challenge, and this struggle will continue and provide sufficient work to the breeders.

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Genetic Enhancement of Tomato Crop for Abiotic Stress Tolerance

11

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Abstract

India being the second largest producer of tomato will still fall short of the country's requirement. The main concern is the decreasing productivity due to negative effects of environmental stresses. Production of tomato is subjected to many abiotic stresses, mainly heat and drought. In order to sustain tomato production with present day challenges, we need to have a thorough knowledge of the plant's reaction toward the stress and develop sufficient genetically enhanced varieties or hybrids which are tolerant and capable of mitigating the stress. Here we have made an attempt to address the challenge thrown to the breeders by the changing climatic scenario.

11.1 Introduction

Tomato occupies a significant position in world vegetable production due to its worldwide consumption. World's acreage of tomato is 43 lakh ha with a productivity of 33.5 tha^{-1}, while in India, it is cultivated in 6.34 lakh ha, with a productivity of 19.33 tha^{-1} (FAO STAT 2010). Changing climatic scenario has resulted in marginal increase/decrease in temperature regimes affecting the normal growing environment of an already adapted cultivar(s) of important vegetable crops. Abiotic stress is the primary cause of crop loss worldwide, reducing average yields for most major crop plants by more than 50% (Boyer 1982; Bray et al. 2000). Abiotic stress leads to a series of morphological, physiological, biochemical, and molecular changes that adversely affect plant growth and productivity (Wang et al. 2001). To maintain growth and productivity, plants must adapt to stress conditions and exercise specific tolerance mechanisms. Plant modification for enhanced tolerance is mostly based on the manipulation of genes that protect and maintain the function and structure of cellular components. Sources of genetic tolerance (or resistance) to different abiotic stresses are found within the related wild species, including *L. chilense, L. peruvianum, L. pennellii, L. pimpinellifolium, L. hirsutum, L. cheesmanii, L. chmielewskii,* and *L. parviflorum* (Foolad 2005). Progress in developing heat-tolerant cultivars has been hindered by the complexity of

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the trait and its low heritability values (Scott et al. 1986; Villareal and Lai 1979). For successful tomato production under environmental stress, tolerance may be needed at all major stages of plant development, including seed germination, the vegetative stage, flowering and fruiting.

Drought is the single most important factor affecting world food security and the catalyst of the great famines of the past (Schonfeld et al. 1988). Drought, defined as the occurrence of a substantial water deficit in the soil or atmosphere, is an increasingly important constraint to crop productivity and yield stability worldwide (Ceccarelli and Grando 1996). At present, an unsustainable 70% of the world's water is used for agriculture. By 2025, it is expected that most Asian countries will join those that already have water shortages. Uncertainties over global warming raise further concerns; thus, it has become a major target of plant research (Sharma and Lavanya 2002).

11.2 Effect of Temperature on Yield and Quality of Tomato

High temperature stress can be caused due to high maximum and/or minimum temperature. Tomato has a base temperature for vegetative development when growth commences, and an optimum temperature when the plant growth reaches the peak of the sigmoid curve. Any change in temperature above or below this optimum temperature will directly and negatively reflect on plant growth. Optimal mean daily temperatures for tomato are between 21°C and 24°C. Tomato is particularly sensitive to short periods of hot temperatures if they coincide with critical stages of the crop development depending on developmental stage (Geisenberg and Stewart 1986; Haque et al. 1999; Araki et al. 2000). Temperature fluctuation of only a few degrees above optimal can reduce fruit production and seed set (Peet et al. 1997). Apart from day temperature, night temperature also plays a crucial role in fruit yield and quality (Iwahori and Takahashi 1964; Abdalla and Verkerk 1968; Rudich et al. 1977; Levy et al. 1978; El Ahmadi and Stevens 1979; Kuo et al. 1979; Hanna and Hernandez 1982). As tomato cultivation is taken all round the year and in arid regions, development of cultivars with improved fruit set under high temperatures is the need of the hour for crop production in regions where the temperature during part of the growing season reaches 35^{0}C or higher (Johnson and Hall 1953; Iwahori 1965, 1966; Stevens and Rudich 1978). Heat stress at vegetative and reproductive stages of the plant ultimately reduces yield and fruit quality (Charles and Harris 1972; Rudich et al. 1977; El Ahmadi and Stevens 1979; Hanna and Hernandez 1982; Yakir et al. 1984; Berry and Uddin 1988;Abdul-Baki 1991; Dane et al. 1991; Wessel-Beaver and Scott 1992).

11.2.1 Germination

Several factors may contribute to reduced set fruit under high temperatures and can be considered as potential selection criteria. Heat stress adversely affects critical steps in the life cycle of a tomato plant. Higher temperatures during seed germination reduces the number of days taken for germination, thereby inhibiting stratification (pre chilling effects). Though not much work has been done in this aspect to see the result of such early emergence, this is one such delayed effect where the response by the plant is after the conclusion of the stimulus. It is one of the most noticeable changes caused by increase in temperature in the life cycle.

11.2.2 Vegetative Stage

Higher growth temperatures result in shorter crop production times, i.e., number of days to harvest (DTH), but with smaller fruit and lower yield (Rylski 1979a, b; Sawheny and Polowick 1985). Differences in temperature during vegetative growth influence the rate of development and timing to first flower. Hurd and Cooper (1970), Grimstad (1995), and Sauser (1998) reported that application of a short 2-week chilling temperature prior to anthesis delayed crop development but resulted in larger individual fruit size. Abdalla and Verkerk (1968) showed set fruit could be severely inhibited by short- and long-term exposure to temperatures in excess of 30°C in certain cultivars (El Ahmadi and Stevens 1979). Other research indicated that the duration, magnitude, and timing of short-term temperature pulses during the growing season influenced fruit development time (Adams and Valdés 2002), firmness, and yield (Mulholland et al. 2003).

Nonreproductive processes affected by high temperature are photosynthetic efficiency (Bar-Tsur et al. 1985; Dinar and Rudich 1985), increase in rate of transpiration, assimilate translocation (Tanaka et al. 1974; Went and Hull 1949), mesophyll resistance (Stevens and Rudich 1978), disorganization of cellular membranes like the thylakoid membrane wherein the photosystem II complexes are located (the most heat-sensitive part of the photosynthetic membrane (Santarius and Weis 1988; Weis and Berry 1988), Rubisco, and other enzymes which participate in carbon metabolism, changes in viscosity levels in the protoplasm and electrolyte leakage from the leaves (Shen and Li 1982) have been observed in response to high temperatures).

At higher temperatures, trusses appear faster (Adams et al. 2001a), and therefore, initially, there are more fruits on a plant at a higher temperature. These will grow at the expense of vegetative growth but may also cause a delay in the growth of newly set fruit and might even lead to flower or fruit abortion (De Koning 1989), as developing and flowering trusses are weaker sinks than fruiting trusses (Ho and Hewitt 1986).

11.2.3 Reproductive Stage

Flowering is the most sensitive stage affected by high temperature. At vegetative stage, the factors that are affected by increase in temperature include reduced flower production (Iwahori and Takahashi 1964; Iwahori 1965, 1966; Sugiyama et al. 1966), reduction in pollen production, reduced ovule and pollen viability, failure of fertilization due to decreases in pollen germination, and pollen tube elongation (Iwahori 1966; Weaver and Timm 1989; Peet et al. 1997; Sato et al. 2000; Pressman et al. 2002; Thomas and Prasad 2003), Splitting of the antheridial cone, stigma, and stylar exsertion is also reported (Rudich et al. 1977; Levy et al. 1978; El Ahmadi and Stevens 1979a). Heat stress not only affected the male gametes and its germination but also adversely affected the ovule development, viability, and development of the embryo (Peet et al. 1988); high temperatures directly cause dehydration of stigma which in turn inhibits pollination. An increase of 2–4°C from the optimal temperature adversely affected gamete development and inhibited the ability of pollinated flowers into seeded fruits and thus reduced crop yields (Peet et al. 1997; Sato et al. 2001; Firon et al. 2006). A brief period of 40°C for 3–4 h 8–9 days before anthesis and 1–3 days after anthesis affected meiosis and fertilization (Iwahori and Takahashi 1964; Iwahori 1965, 1966; Sugiyama et al. 1966). Critical period of sensitivity to moderate high temperature (32/26°C) is 7–15 days before anthesis (Sato et al. 2002). The reduction of set fruit under moderately high temperature stress is mostly due to a reduction in pollen release and viability but not in pollen production (Sato et al. 2006). The numbers of pollen grains produced by the heat-tolerant genotypes were higher than those of sensitive genotypes (Abdelmageed et al. 2003), and this criterion can be used for selection of heat-tolerant lines from a germplasm collection.

11.2.4 Fruit/Yield

Plants exposed to a fluctuating temperature regime often suffer no overall loss of yield when compared with those grown in a constant regime having the same mean temperature (Hurd and Graves 1984; Khayat et al. 1985; de Koning 1988, 1990). However, fluctuation in temperature may affect the pattern of crop yield as the rate of developmental events such as fruit maturation and volume is determined largely by temperature (Hurd and Graves 1985). Elevated temperature often increases the fruit growth rate, but it has a greater effect in hastening maturity, and as a result, the response of the plant is exhibited by compensating the final mean weight of tomato fruits (Hurd and Graves 1985; Sawhney and Polowick 1985).

Furthermore, temperature extremes can inhibit the ripening process (Lurie et al. 1996; Adams et al. 2001). Due to an increasing need to be able to schedule the crops with precision to meet stringent retail demands, heat stress acts as a constraint for continuity of high-quality product output to the market by a farmer.

11.3 Genetic Resources for Stress Tolerance

Efforts to introduce heat tolerance to the heat-sensitive commercial cultivars have prompted interest in developing criteria for evaluating germplasm from domesticated and wild species for heat tolerance. Identification of genetic resources with stress tolerance is a prerequisite for a sound breeding program in evolving stress-tolerant varieties/hybrids.

Tomato	Fla. 7156, Fla. 7771, Fla. 7776, CL-5915, CLN-1621 F, Red Cherry, Nagcarlan, Beaverlodge-6804 & 6806, *L. esculentum* var. *cerasiforme* (PI 190256), Fresh Market 9, Saladette, Processor 40, Solar Set, CLN5915-206, CLN2498D, CLN2413D, CLN2366A & CLN2123C

11.4 Biochemical Parameters of Abiotic Stress

The quality of the harvested fruit is of major concern to growers because fruit is graded according to external attractiveness (e.g., color, size, shape, and skin defects) or internal characteristics such as taste and texture (Guichard et al. 2001; Shi et al. 2002). Gautier et al. (2005) reported decreases in sugar and lycopene content in cherry tomato when fruit temperatures were increased by approximately 1 °C following fruit set through harvest under high fruit load. However, the majority of studies on the influence of temperature on fruit quality parameters have focused on postharvest fruit ripening (e.g., Dalal et al. 1968, Lurie et al. 1996). The rate of starch biosynthesis, which influences sink-strength, and thus final fruit size and yield, is potentially at its highest levels the first 10–35 d following fruit set (Ho 1996; Walker et al. 1978). Temperature changes during this time may also affect fruit maturation and growth by influencing regulation of the enzyme's acid invertase and sucrose synthase or cell expansion and division (Guichard et al. 2001; Ho and Hewitt 1986) and regulation of sugar transport into the fruit (Ho 1996).

11.4.1 Effect of Drought on Yield and Quality of Tomato

Tomato plant is sensitive to water deficits during and immediately after transplanting, at flowering stage, and during fruit development (Doorenbos and Kassam 1979). Water consumption remains constant until the onset of ripening after which, in determinate varieties, it decreases (Rudich and Luchinsky 1986). The growing season can be divided into 5 stages, viz, germination, vegetative growth stage, reproductive stage, fruit development and ripening stage.

The first organ/system to be affected by drought is the root system, wherein the root tips are the actual sensors of stress. Evidence leading to prove that the root tip experiences a loss in turgor much earlier than the root (Zhang et al. 1987). Production of ramified root system under drought is important to aboveground dry mass, and the plant species or varieties of a species show great differences in the production of roots (Jaleel et al. 2009). Tomato plants tend to show denser root system at soil water potentials which are slightly less than field capacity (Miche-lakis and Chartzoulakis 1988). The importance of root systems in acquiring water has long been recognized. The relative root growth may undergo enhancement, which facilitates the capacity of the root system to extract more water from deeper soil layers. Samuel and Paliwal (1994) observed that the water-stressed plants (tomato cv.PKM-1) showed a drastic reduction in tissue water content compared with the control plants.

The most obvious morphological effect is growth inhibition, i.e., reduction in vegetative growth, in particular shoot growth. Leaf growth is generally more sensitive than the root growth. In contrary to root, reduced leaf expansion, accelerating senescence, and abscission of the older leaves are beneficial to plants under water-deficit condition, as less leaf area is exposed resulting in reduced transpiration (Shinohara et al. 1995). Water deficit leads to decrease in the number of flowers and consequently the number of fruit and ultimately to less marketable yield (Losada and Rincaon 1994; Colla et al. 1999; Rahman et al. 1999; Veit-Kohler et al. 1999). Reduction in the size of the fruit is also observed in tomato (Adams 1990).

It has been observed that irrigation at reproductive and fruit development stages led to a 120% increase in yield (Rudich et al. 1977). A range between 300 and 400 mm of irrigation is essential for good fruit (Silva and Marouelli 1996) and between 400 and 600 mm during 90–120 days of the plant life cycle (Doorenbos and Kassam 1979).

In a situation where water deficit becomes too intense or prolonged, plants can wilt, cells can undergo shrinkage, and this may lead to mechanical constraint on cellular membranes. The strain on membrane is one of the severe effects of drought implicated on plant physiology (Shilpi and Narendra 2005).

The highest demand for water in tomato plant is during flowering (Doorenbos and Kassam 1979). Regular irrigation is vital for optimum yield (Helyes et al. 1999). Ripening is the most sensitive stage and any heterogeneous distribution of irrigation leads to fruit cracking (Losada and Rincaon 1994). Lapushner et al. (1986) observed that the fruit weight of tomato was reduced by water stress.

Blossom-end rot (BER) of tomatoes is a common problem occurring under conditions of water stress and heavy fruit load (Hodges and Steinegger 1991). It appears as brown to black lathery spots of the underside/blossom end of the fruit of tomatoes which eventually leads to decay of fruits (Sanders et al. 1989). Even a temporary water stress during early fruit enlargement can cause BER because the fruits are the last to receive adequate calcium (Hodges and Steinegger 1991). Reid et al. (1996) observed a greater incidence of internal blackening and BER, and lower concentration of calcium, in nonirrigated plants than that of irrigated plants. Calcium movement in the roots depends mainly on soil moisture.

11.4.2 Biochemical Parameters

Consumer acceptance being the ultimate goal of a breeding program, tomato breeders have to constantly try not only to increase the yield potential of their hybrids or varieties but also have to retain and improve the flavor component of the fruit under drought conditions (Stevens et al. 1977).

Certain metabolic processes are triggered in response to stress, which increase the net solute concentration in the cell, thereby helping the movement of water into the leaf resulting in increased leaf turgor. Large numbers of compounds are synthesized, which play a key role in maintaining the osmotic equilibrium and in the protection of membranes as well as macromolecules. These compounds include proline, glutamate, glycine betaine, carnitine, mannitol, sorbitol, fructans, polyols, trehalose, sucrose, oligosaccharides, and inorganic ions like K+. These compounds help the cells to maintain their hydrated state and therefore function to provide resistance against drought and cellular dehydration (Hoekstra et al. 2001; Ramanjulu and Bartels 2002).

Quality of the fruit in terms of total soluble solids, acidity (May 1993; Shinohara et al. 1995; Colla et al. 1999; Veit-Kohler et al. 1999), viscosity, and vitamin C is improved by water deficit (Rudich et al. 1977; Veit-Kohler et al. 1999; Zushi and Matsuzoe 1998). Though high sugar content in tomato is a desirable character which can be achieved by decreased irrigation (Imada et al. 1989; Veit-Kohler et al. 1999), on the contrary the overall yield is drastically reduced. A decrease up to 20% irrigation or even lesser percentage of irrigation shows significant improvement in tomato fruit flavor components (Veit-Kohler et al. 1999). Accelerated development of color and increased amount of beta-carotene content in cherry tomato due to water deficit is observed. Water deficit leads to reduction in tomato fruit size (Adams 1990), thereby reducing the locular size and the capacity of the fruit to accumulate acids and sugars, which eventually leads to poor flavor (Stevens et al. 1977).

11.4.3 Selection of Genotypes for Water Stress Tolerance

Tissue tolerance to severe dehydration is not common in crop plants but is found in species native to extremely dry environments (Ingram and Bartels 1996). Selection of genotypes for drought tolerance in water-limited environments can result in populations or species with suites of traits that improve their relative fitness in response to drought (Dudley 1996; McKay et al. 2001, 2003; Chaves et al. 2003; Juenger et al. 2005). Such traits, including acclimation responses, can improve tolerance of tissue desiccation allowing leaves to persist and function longer into drought periods or improve avoidance of water loss, allowing leaves to maintain high water potential during drought (Ludlow 1989; Kramer and Boyer 1995).

High yield potential under drought stress is the target of crop breeding. In many cases, high yield potential can contribute to yield in moderate stress environment (Blum 1996).

Genetic variability for drought tolerance in *Solanum lycopersicum* is limited and inadequate. Direct selection in the field is not always possible because uncontrollable environmental factors, such as variations in rainfall, interactions with extreme temperatures, and variations in salinity and nutrient availability, adversely affect the precision and repeatability of such trials (Richards 1996). There is no reliable field screening technique that could be used year after year and generation after generation. Selection and breeding for drought tolerance is also difficult because tolerance is a developmentally regulated, stage-specific phenomenon (Ludlow and Muchow 1990; Richards 1996).

The best source of resistance is from other species in the genus Solanum. In the Tomato Genetics Resource Center (TGRC) at the University of California, Davis has assembled a set of the putatively stress-tolerant tomato germplasm that includes accessions of *S. cheesmanii*, *S. chilense*, *S. lycopersicum*, *S. lycopersicum* var. *cerasiforme*, *S. pennellii*, *S. peruvianum, and S. pimpinellifolium*, *S. chilense*, and *S. pennelli* are indigenous to arid and semiarid environments of South America. Both species produce small green fruit and have an indeterminate growth habit. *S. chilense* is adapted to desert areas of northern Chile and often found in areas where no other vegetation grows (Rick 1973; Maldonado et al. 2003) *S. chilense* has finely divided leaves and well-developed root system (Sánchez Peña 1999). *S. chilense* has a longer primary root and more extensive secondary root system than cultivated tomato (O'Connell et al. 2007). Drought tests show that *S. chilense* is five times more tolerant of wilting than cultivated tomato. S. pennellii has the ability to increase its water use efficiency under drought conditions unlike the cultivated *S. lycopersicum* (O'Connell et al. 2007). It has thick, round waxy leaves and is known to produce acyl-sugars in its trichomes, and its leaves are able to take up dew (Rick 1973). Studies comparing drought response in S. pennellii, a self-incompatible species from the driest environments, to *S. lycopersicum*, the self-compatible cultivated tomato, have shown that S. pennellii had higher water use efficiency (WUE) both in water-stressed and nonstressed conditions (Kebede et al. 1994; Martin et al. 1999). Interestingly, *S. pennellii* and *S. lycopersicum* had similar night time stomatal opening when well watered (Caird et al. 2007a, b). *Solanum pennellii* also reduced leaf conductance (g) more rapidly in response to drought, allowing it to maintain higher leaf water potential (Ψ l) compared to *S. lycopersicum* (Torrecillas et al. 1995). The differential drought responses of *S. pennellii* and *S. lycopersicum* suggest that adaptation to diverse habitats may have played a role in speciation processes in wild tomatoes (Schluter 2001; Levin 2005; Nakazato et al. 2008). Indeed local adaptation to habitat water availability has been shown in other herbaceous species. In studies of sapphire rock cress and dandelion, populations from drier environments had a higher WUE than populations from wetter conditions in common garden experiments (McKay et al. 2001; Brock and Galen 2005). These differences in intrinsic, drought-related traits suggest there may be differences in physiological responses to drought among populations when habitats differ in water availability. An advanced drought-tolerant line (RF4A) has been developed at Indian Institute of Horticultural Research by interspecific hybridization with *S. pennellii*.

Sources of resistance to drought have been reported in several accessions of wild taxa which includes LA0429 (*S. cheesmaniae* Ecuador), LA1401 (*S. cheesmaniae* Ecuador), LA3661 (*S. chmielewskii* Peru), LA2680 (*S. chmielewskii* Peru), LA1334 (*S. lycopersicum* var. *cerasiforme* Peru), LA1421 (*S. lycopersicum* var. *cerasiforme*), LA2133 (*S. neorickii* Ecuador), LA3657 (*S. neorickii* Peru), LA1335 (*S. pimpinellifolium* Peru), LA1416 (*S. pimpinellifolium* Ecuador), and RF4A (*S. pennellii* derived, IIHR, India).

11.4.4 Water Management

On an average, water use efficiency in the existing irrigation project in India is only about 40%. A bulk of water meant for agricultural use in fact does not benefit crops. With better water management, if the efficiency is improved to the level of 60%, it will allow an additional 8 million hectare of land under irrigation with the existing irrigation facilities alone in India (Bhagavantha-goudra 2000). The quality of tomato can be enhanced, and water can be saved by using well-managed drip irrigation system (Rudich et al. 1977). Water requirement of tomato changes according to the stage of the crop; therefore, an irrigation regime ideal for tomato should be arrived at to meet the demand of water by the plant.

11.5 Conclusion and Future Prospects

To address the impact of heat stress (Ainsworth et al. 2008), breeding new cultivars with enhanced adaptation to high temperatures will help farmers grow crops in stressful environments of the twenty-first century. Low heritability values, complexity of the trait, and environmental factors such as relative humidity are a few constrains encountered in developing tolerant lines (Scott et al. 1986; Villareal and Lai 1979; Abdalla and Verkerk 1968) through conventional breeding. Genetic resources and breeding methods combining conventional and molecular tools (including the transgenic approach) are needed to develop such cultivars. However, as indicated by Bonhert et al. (2006), abiotic stresses such as temperature extremes, water scarcity, and ion toxicity (e.g., salinity and heavy metals) are difficult to dissect because defense responses to abiotic factors require regulatory changes to the activation of multiple genes and pathways. Nevertheless, recent advances in genomic research addresses this problem in a more integrated manner with the multigenicity of the plant abiotic stress response.

Drought stress is an important area with respect to increase in plant productivity. Therefore, the basic understanding of the mechanisms underlying the functioning of physiological, biochemical, and molecular aspects is important for the development of tolerant tomato plants. Accumulating evidence suggests that plant response to drought stress is controlled by more than one gene and is highly influenced by environmental variation (Ceccarelli and Grando 1996; Richards 1996). A deeper understanding of the transcription factors regulating these genes, the products of the major stress responsive genes, and cross talk between different signaling components should remain an area of intense research in future. Transfer and utilization of genes from these drought resistant species will enhance tolerance of tomato cultivars to dry conditions, although wide crosses with *S. pennellii* produce fertile progenies, *S. chilense* is cross incompatible with *S. lycopersicum*, and embryo rescue through tissue culture is required to produce progeny plants. The knowledge generated through these studies should be utilized in making transgenic plants that would be able to tolerate stress condition without showing any growth and yield penalty. Therefore, it is desirable that appropriate stress-inducible promoters should drive the stress genes as well as transcription factors, which will minimize their expression under a nonstressed condition, thereby reducing yield loss. The product of these genes should also be targeted to the desired tissue as well as cellular location to control the timing as well as intensity of expression. Attempts should be made to design suitable vectors for stacking relevant genes of one pathway or complementary pathways to develop durable tolerance. These genes should preferably be driven by a stress-inducible promoter to have maximal beneficial effects. Additionally, due importance should be laid on the physiological parameters such as the relative content of different ions present in the soil as well as the water status of the crop in designing transgenic plants for the future.

The ultimate goal is to develop plants with improved water use efficiency, resulting in crops that could significantly increase their yield and alleviate an increasingly imminent threat of food scarcity. Drought stress tolerance can not only improve the productivity of the land already in use but may also permit the exploitation of cultivable land with limited water supplies and in areas where cultivation was not practiced. Research is in progress to identify the genetic factors underlying drought tolerance in *S. chilense* and *S. pennellii* and to transfer these factors into cultivated tomatoes.

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Impact of Climate Change on Potato

12

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Abstract

Potato, a native of temperate region was introduced in India and adapted to tropical short-day conditions where it covers >80% of total potato area. The crop is very sensitive to climatic variability, and therefore, the climate change and global warming will have a profound effect on potato growth in India. Even moderately high temperature drastically reduces tuber yield without much affecting the photosynthesis and total biomass production. Besides, high temperature affects tuber quality by causing heat sprouting and internal necrosis. The effect of elevated CO_2 concentration suggests positive effect on growth and yield with only few negative influences. Study on the impact assessment of climate change on potato production using INFOCROP-POTATO model showed that the potato production will increase by 11.12% at elevated CO_2 of 550 ppm and 1°C rise in temperature but further increase in CO_2 to 550 ppm with a likely rise in temperature to 3°C will result in decline in potato production by 13.72% in the year 2050. The effect of elevated temperature on late blight at global level revealed that with rise in global temperature of 2°C, there will be lower risk of late blight in warmer areas (<22°C) and higher risk in cooler areas (>13°C) with early onset of the epidemics. Global warming will have a serious repercussion on viral diseases through the altered biology of insect vectors. The increase in temperature will enhance vector population thereby increasing the number of insecticide sprays for keeping the vector population in check. The effects of temperature and CO_2 on potato growth and development, productivity, diseases and insect pests, and quality have been discussed in the present communication. Besides, regional vulnerability to climate change and adaptation measures for climate change and global warming are also discussed.

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12.1 Introduction

Climate change is now an acknowledged fact and reality. The rate of global warming in last 50 years is double than that for the last century. As many as 11 of the past 12 years were warmest since 1850, when records began. As per the IPCC 4th Assessment report which was released in 2007, it is expected that in South Asia, the mean temperature increase will range from 0.54 during June, July, and August to 1.18°C in March, April, and May with corresponding change in precipitation of 5% and 7%, respectively, by 2020 under A1FI scenario. These changes in temperature are expected to aggravate and range from 1.71 during June, July, and August to 3.16°C during December, January, and February in 2050, while the change in precipitation is expected to range from 0 during December, January, and February to 26% in March, April, and May in A1FI scenario. The potato crop in India is mainly confined to Indo-Gangetic plains where it is grown during the mild and cool winters. The autumn/winter planted crop in northern plains of India comprising the states of Uttar Pradesh, West Bengal, Bihar, Punjab, and Haryana contributes 84% of total potato production in India. As per the climate change scenario of South Asia, an increase in temperature ranging from 0.78 during September, October, and November to 1.18°C during December, January, and February is expected under A1FI scenario by 2020, while the corresponding change in precipitation is expected to be 1 and −3%, respectively. Thus, by 2020 the potato season is likely to be a little warmer and also slightly drier. The crop is also grown in small scattered areas as rainfed crop in hills during summers and as rainy (*kharif*) and winter seasons crop in plateau region. The increase in temperature during the kharif season is expected to be lesser than in the plains, i.e. 0.54°C during June, July, and August with corresponding precipitation increase of 5% under A1FI scenario. There is a need to study the impact of these changes in temperature and precipitation and devise adaptation strategy to minimize the impact.

12.2 Impact Analysis

12.2.1 Impact on Potato Growth and Development and Productivity

Growth and development is affected at exceptionally high temperatures encountered in the tropics. Increase in temperature and atmospheric CO_2 are interlinked, occurring simultaneously under future climate change and global warming scenarios. Effect of their interaction on potato would be more relevant and of greater economic significance compared to their usually counteracting direct effects on crop growth, yield, and quality.

12.2.1.1 Effect of Temperature

Temperature affects the growth and development of potato. The reported cardinal temperatures are minimum (0–7°C), optimum (16–25°C), and maximum (40°C) temperatures for net photosynthesis (Kooman and Haverkort 1995). Temperature, especially soil temperature also affects the establishment phase. The optimum temperature for emergence has been reported to be between 22°C and 24°C (Sale 1979), and up to this temperature, the emergence rate increases linearly with increase in temperature. Temperature below 20°C delays sprouts growth (Firman et al. 1992). Temperatures higher than the optimum also reduce sprout growth (Midmore 1984). The slower emergence rate at higher than optimum temperature is reported to be due to subapical necrosis arresting sprout growth (McGee et al. 1986).

High temperature would alter the morphological attributes of the crop leading to etiolated growth with smaller size of compound leaves and leaflets reducing the LAI (Ewing 1997; Fleisher et al. 2006). The rate of leaf appearance is linearly correlated with temperature in 9–25°C range, and no further increase occur beyond 25°C (Kirk and Marshall 1992), whereas, 25°C was also found to be optimum for leaf expansion (Benoit et al. 1983). At very high temperatures, leaves do not expand fully thereby reducing light interception. Prange et al. (1990) observed that though the leaf area was less under warm conditions, the dry weight of the leaves was not affected indicating that the leaf expansion was reduced. Therefore, genotypes grown in hot conditions have lower specific leaf area (Midmore and Prange 1991). Hence in potato models, leaf expansion has been considered to increase linearly up to 24°C, thereafter decreasing linearly to 0 at 35°C (Kooman and Haverkort 1995). Stem elongation is also affected at high temperatures. The relation between stem elongation and temperature is almost linear up to 35°C (Manrique 1990) and is stimulated by high day and low night temperatures, while at high night temperatures, branching is promoted (Moreno 1985). Thus, yield is reduced at high temperatures due to lower ground-cover duration which has been reported to be positively correlated with yield (Van der Zaag and Demangante 1987) because yield is a product of intercepted radiation and radiation/light use efficiency. Early establishment of complete canopy cover as well as its continuance for a longer period ensures greater interception of radiation leading to higher yield.

Potato requires cool night temperature to induce tuberization (Burt 1964; Ku et al. 1977; Cutter 1992). Although photosynthesis in potato is suppressed by high temperature (Ku et al. 1977), it is not as sensitive as tuberization and partitioning of photosynthates to tuber (Reynolds et al. 1990; Midmore and Prange, 1991). Therefore, even moderately high temperature drastically reduces tuber yield without much affecting the photosynthesis and total biomass production (Peet and Wolfe 2000).

In addition to biomass production *per se*, its translocation to the tubers is also reduced at high temperatures. The rate of translocation of photosynthate into storage organs is determined mainly by temperature. Plants growing under warm conditions are taller with higher stem to leaf and lower tuber to stem dry matter ratios (Ben Khedhar and Ewing 1985). At 28°C only 50% of assimilates produced were translocated into the tubers, whereas, at 18°C more than two-thirds of the assimilates were translocated (Randeni and Caesar 1986). Thus, at higher temperatures, tops get priority over the tubers for assimilates leading to an increased haulm growth and reduced tuber yield. Pushkarnath (1976) reported night temperature between 12°C and 18°C to be ideal for high yield.

High temperature affects tuber number and size also (Ewing 1997). It can also affect tuber quality by causing 'heat sprouting' which is premature growth of stolons from immature tubers (Wolfe et al. 1983; Struik et al. 1989) and internal necrosis (Sterrett et al. 1991). Potato processing requires large size tubers with high dry matter. Warming may reduce proportion of marketable and processing grade tubers for table and processing purposes.

In addition, vegetative-propagated potato crop needs disease-free quality seed tubers as planting material. Viral diseases transmitted by aphid and other vectors are mainly responsible for rapid degeneration of planting materials in potato crop. The technology of '*seed plot technique*' was developed on the sole promise of growing seed tubers in relatively aphid-free periods in plains during winters, and termination of vines by dehaulming before aphid population crosses a threshold so as to minimize infection of viral diseases. The appearance of potato peach aphid (*Myzus persicae*) is reported to advance by 2 weeks for every 1°C rise in mean temperature, and population build-up is positively correlated with maximum temperature and minimum relative humidity (Dias et al. 1980; Biswas et al. 2004). The earlier appearance and increase in aphid population under the impact of climate change and global warming is likely to decrease the aphid-free period which may affect potato production in India.

Moreover, the harvesting of potato in plains of India coincides with onset of hot summer season. Cold storage of tubers is recommended by the end of February up to the end of October or till withdrawal for planting or ware purposes. Under global warming scenarios, cold storage earlier than recommended, i.e. by the end of February and prolonged storage beyond October, i.e. till weather is favourable for planting, might become necessary.

12.2.1.2 Effect of Elevated CO_2

The effect of elevated CO_2 concentration studied in controlled experiments such as OTC (open top chambers), FACE (free air carbon dioxide enrichment) and growth chambers overwhelmingly suggests positive effect on growth and yield with only a few negative influences.

The CO_2 concentration and assimilation are positively correlated. Doubling the CO_2 concentration from ambient level of 360–720 ppm increased the total biomass by 27–66% (Collins 1976; Wheeler et al. 1991; Van de Geijn and Dijkstra 1995; Miglietta et al. 1998; Donnelly et al. 2001; Olivo et al. 2002; Heagle et al. 2003). At tuber initiation, elevated CO_2 (680 ppm) induced a 40% increase in the light-saturated photosynthetic rate of fully expanded leaves in the upper canopy of cv. Bintje in OTC. This effect resulted from a combination of a 12% reduction in stomatal conductance and a decline in photosynthetic capacity (Vandermeiren et al. 2002). The tuber yield increased from 32% to 85% (Collins 1976; Wheeler et al. 1991; Miglietta et al. 1998; Schapendonk et al. 2000; Donnelly et al. 2001; Craigon et al. 2002; Olivo et al. 2002; Finnan et al. 2002; Heagle et al. 2003; Conn and Cochran 2006) due to increased CO_2 concentration. Using a simple simulation model for potato growth, Wolf and Oijen (2003) calculated tuber yields of irrigated potato (cv. Bintje) for both historical climate conditions and changed climate conditions as based on climate scenarios for year 2050. He reported that climate change gave increases in irrigated yields of 2–4 t/ha dry matter in most regions of the EU, mainly due to the positive response to increased CO_2. The rate of increase in tuber yield due to increase in CO_2 is estimated to be approximately 10% for every 100 ppm increase in CO_2 concentration (Miglietta et al. 1998). These positive effects are attributed to increased photosynthesis from 10% to 40% (Collins 1976; Schapendonk et al. 2000; Olivo et al. 2002; Vandermeiren et al. 2002; Katny et al. 2005). The increase in photosynthesis was most marked in young leaves (Vandermeiren et al. 2002; Katny et al. 2005), and this has been attributed to photosynthetic acclimation later in the growing season particularly in old leaves (Schapendonk et al. 2000, Lawson et al. 2001; Vandermeiren et al. 2002). Varietal differences in response to elevated CO_2 concentration exists (Olivo et al. 2002) so also with nutrition. Doubling CO_2 over the ambient concentration had the greatest effect on dry matter yield under good nutrient supply, but under nitrogen shortage, small negative reaction to CO_2 enrichment was observed (Goudriaan and Ruiter 1983).

Under elevated CO_2 tuber number remained unaffected but means tuber weight increased mainly through increase in number of cells in tubers without influencing the cell volume (Collins 1976; Donnelly et al. 2001; Chen and Setter 2003). However, other workers have reported an increase in tuber number also (Miglietta et al. 1998; Craigon et al. 2002).

Elevated CO_2 concentration has been reported to advance the tuber initiation and flowering (Miglietta et al. 1998) but hasten senescence of leaves (Vaccari et al. 2001), and the relationship between leaf senescence and atmospheric CO_2 levels was found to be linear up to 660 ppm (Miglietta et al. 1998). Further elevated CO_2 concentration has been reported to reduce chlorophyll content in leaves particularly during later growing season after tuber initiation (Lawson et al. 2001; Bindi et al. 2002).

Doubling CO_2 concentration is reported to reduce stomatal conductance by 59% in potato, though this reduction did not limit the net photosynthetic rate, which increased by approximately 53%. Thus, the transpiration rate was reduced by 16%, while instantaneous transpiration efficiency increased by 80% (Olivo et al. 2002). The water saving due to reduction in evapotranspiration (ET) up to the extent of 12–14% has been reported (Olivo et al. 2002; Magliulo et al. 2003).

12.2.1.3 Effect of Elevated CO_2 and Temperature on Productivity

Study on the impact assessment of climate change on potato production was made using INFOCROP-POTATO model (Singh et al. 2005, 2008) without adaptations (Table 12.1). Results showed that the potato production will increase by 11.12% at elevated CO_2 of 550 ppm and 1°C rise in temperature. However, the future climate scenarios for India indicate that in the year 2050, the atmospheric CO_2 concentration will be 550 ppm with a likely increase in temperature to be 3°C (IPCC 2007). Under this scenario a decline in potato production by 13.72% is expected in the year 2050.

Table 12.1 Change (%) in potato production in India from current levels as affected by elevated CO_2 and rise in temperature without adaptations

	Rise in temperature (°C)					
Atmospheric CO_2 conc. (ppm)	Nil (current)	1 (2020)	2	3 (2050)	4	5 (2090)
369 (current)	0.0	−6.27	−17.09	−28.10	−42.55	−60.55
400 (2020)	3.40	−3.16	−14.57	−25.54	−58.63	−58.63
550 (2050)	18.65	11.12	−1.25	−13.72	−30.25	−49.94

Values in parentheses are likely years for associated CO_2 levels and temperature rise
Source: (Singh et al. 2009)

The expected 1°C rise in temperature associated with 400 ppm of CO_2 in the year 2020 (IPCC 2007) will result in a decline potato production by 3.16%, without adaptation (Table 12.1).

12.2.2 Impact on Potato Diseases and Insect Pests

The three legs of the 'plant disease triangle', namely, the host, pathogen, and environment must be present and interact appropriately for plant disease to appear. If any of the three factors is altered, changes in the progression of a disease epidemic can occur. The climate change and global warming with increases in temperature, moisture, and CO_2 levels can impact all three legs of the plant disease triangle in various ways. Climate change and global warming will allow survival of plants and pathogens outside their existing geographical ranges. Northward and southward range shifts in insect pests, and diseases with warming is indicated in the Northern and Southern Hemispheres, respectively (Sutherst and Maywald 1990; Coakley et al. 1999). Since the potato-growing regions of the world is expected to be warmer and wetter, the potato pathogens, especially late blight pathogen, would become more important because the pathogen is strongly dependent on climatic factors for infection and sporulation.

12.2.2.1 Effect of Elevated Temperature

Late Blight

Late blight (*Phytophthora infestans*) is the most serious disease of potato that causes approximately $US 13 billion losses in developing countries. Studies conducted at CIP, Peru, to work out the risk of late blight (expressed as number of sprays) at global level climate change scenario revealed that with rise in global temperature of 2°C, there will be lower risk of late blight in warmer areas (<22°C) and higher risk in cooler areas (>13°C). Earlier onset of warm temperatures could result in an early appearance of late blight disease in temperate regions with the potential for more severe epidemics and increased number of fungicide applications needed for its control. Studies carried out in Finland predicted that for each 1°C warming, late blight would occur four to seven days earlier, and the susceptibility period extended by 10–20 days (Kaukoranta 1996). This would result in 1–4 additional fungicide applications, increasing both cost of cultivation and environmental risk. In India also the late blight scenario would change drastically with climate change. Currently, late blight is not a serious problem in autumn in the state of Punjab, Haryana, and parts of Uttar Pradesh, primarily due to suboptimal temperature regimes during December–January. However, disease outbreaks will become more intense with increase in ambient temperature coupled with high RH. Such scenarios have been witnessed during warmer years, i.e. 1997–98 and 2006–2007, when average crop losses in this region exceeded 40%. States like Madhya Pradesh, Gujarat, and Central Uttar Pradesh, which are comparatively free from late blight attack may witness frequent outbreaks of the disease under the climate change scenario. Increase in both, temperature and RH has added new dimension to late blight across the world. Under such a situation, *P. infestans* attacks potato stems more often than foliage. In fact, in recent years it is more of 'stem blight' than the foliar blight. This phase of the disease is more serious than the foliar stage as it affects the very crop plant. In Upper Great Lakes region of the USA, increase in annual precipitation and increase in number of days with precipitation over the years is supposed to be the reason for the increased risk of potato late blight infection and subsequent yield and economic losses. In India, in Lahaul valley of HP, which was earlier free from late blight because of lack of precipitation, has now experienced attack of late blight due to occurrence of rainfall. However, hotter and drier summers which are likely in the UK may reduce the importance of late blight, although earlier disease onset may obviate this advantage. An empirical climate disease model has suggested that under the climate change scenario of 1°C increase with 30% reduction in precipitation in Germany will decrease potato late blight to a mere 16% of its current level.

Soil Borne Pathogens

The effect of climate change on soil borne pathogens would vary from pathogen to pathogen. *Synchytrium endobioticum* causing wart and *Spongospora subterranea* responsible for powdery scab are favoured by low temperature and high soil moisture. Wart spores although can cause infection in the range of 10–28°C with an optimum of 21°C, but there is hardly any infection beyond 23°C. Therefore, warmer climates are likely to reduce wart infestation. Powdery scab infestation is also likely to be reduced with increase in temperature and reduction in rainfall as a consequence of global warming. Since optimum temperature for powdery scab is 12°C, and moisture requirement is 100%, the global warming may either lead to elimination of this disease or it will be pushed to higher altitudes making high hills (2,500 masl) free of powdery scab. Diseases like *Sclerotium* wilt, charcoal rot, and bacterial wilt are favoured by high temperature and moisture. *Sclerotium* wilt in India is restricted to plateau regions (Madhya Pradesh, Karnataka, Maharashtra). Optimum temperature requirement for this disease is 30–35°C. With the increase in temperature due to global warming, the disease may enter into other areas like mid-hills, and in long run, it may also become prevalent in eastern Indo-Gangetic plains. Similarly, bacterial wilt may also advance to higher altitudes in hilly regions due to global warming, making them unfit for seed production.

Charcoal rot is currently endemic in eastern Uttar Pradesh, Bihar, and Madhya Pradesh. The global warming is likely to increase the severity of this disease in these regions. It is also likely to expand to other parts of North Central plains as well. Black scurf and common scab are favoured by moderate temperatures (15–21 and 20–22°C, respectively) and are likely to remain insulated from global warming in near future. By the end of the century when ambient temperatures are likely to increase by 1.4–5.8°C, the severity of these two diseases may decrease substantially.

Viral Diseases

The rate of multiplication of most of the potato viruses gets increased with the increase in temperatures. In the subtropical plains, where majority of the potatoes are grown, global warming may not affect potato viruses directly, but may have a serious repercussion through the altered biology of insect vectors. The increase in temperature will enhance vector population, thereby increasing the number of insecticide sprays for keeping the vector population in check. Rate of multiplication of the virus in host tissue will also increase substantially, leading to early expression of the virus symptoms. Studies carried out in Holland revealed that during the last 12 years (1994–2008), some new viral strains (PVY^{ntn}, PVY^{nw}) have been detected indicating that climate change may introduce new viral strains.

As regards insects, *Bemisia tabaci* was a minor pest till recently in India. Data on population build-up during the last 20 years revealed that average population of *B. tabaci* was 11 whitefly/100 leaves during 1984 which rose to 24.24 in 2004. During this period, average ambient temperature increased by 1.07°C. This indicates that warming may lead to whitefly infestation in Indo-Gangetic plains. Increase in *B. tabaci* population has also led to outbreak of a new viral disease known as Apical leaf curl in potato which has since been identified to be caused by a Gemini virus which is not reported to infect potato crop world over. Therefore, a new dimension has been added to seed potato production in subtropics.

Results also tend to suggest that in subtropical plains of India, *Myzus persicae* population is on the rise. During 1984–1985 mean aphid population/100 compound leaves were 567 which increased to 653 in 2003–2004. Besides, aphid appearance advanced by 5 days during last 20 years, reducing the low aphid pressure window for seed production from 80 to 75 days. On the other hand, population of *Aphis gossypii* has increased threefold during the last 20 years. Although *A. gossypii* has low vector efficiency, its appearance right from the emergence of the crop and further maintaining its population throughout the crop season may pose serious problems to seed production in subtropical plains.

Leaf hopper (*Empoasca fabae*) is another pest which has assumed significance in early planted crop in subtropical plains of India. Its population during 1984 was 16.6 which rose to 23.8 in 2004. The hopper burn damage also increased from 45% to 68% during this intervening period. Mite infestation has also increased in early planted crop. During 1984–1985 its damage was 86% which increased to 100% in 2004.

12.2.2.2 Effect of Elevated CO_2

Not much information is available on the impact of elevated CO_2 on potato diseases. However, a general outline has been drawn from the available literature on the effect of elevated CO_2 on plant diseases. The increase in CO_2 will probably have little direct effect on most pathogens, as many soil-inhabiting fungi can tolerate more than 10- or 20-fold increases in CO_2, and might even be slightly stimulatory (Manning and Tiedemann 1995). Chakraborty et al. (2000) suggest that the impact of increased CO_2 concentrations on plant diseases will likely be through changes in host physiology and anatomy, such as lowered nutrient concentration, greater accumulation of carbohydrates in leaves, more waxes, extra layers of epidermal cells and increased fibre content, and greater number of mesophyll cells. They further reported that two important trends have emerged in the effects of elevated CO_2 on host–pathogen interactions: (1) initial establishment of a pathogen may be delayed because of modifications in pathogen aggressiveness and/or host susceptibility and (2) increased fecundity of pathogens. The combination of increased fecundity and a more humid microclimate within dense crop canopies associated with increased CO_2 concentrations might provide more opportunities for severe infection. Pathogen growth can be affected by higher CO_2 concentrations resulting in greater fungal spore production. However, increased CO_2 can result in physiological changes to the host plant that can increase host resistance to pathogens as well. Work on the effect of elevated CO_2 on potato pests is scanty. Studies carried out by Bezemer et al. (1998) revealed that aphid abundance was enhanced by both the CO_2 and temperature. Parasitism rates remained unchanged in elevated CO_2 but showed an increasing trend in conditions of elevated temperature.

12.2.3 Impact on Quality

The CO_2 enrichment does not appear to compensate for the detrimental effects of higher temperature on tuber yield, while the quality of potato is likely to be impacted severely in terms of marketable grade of tubers and internal disorders.

Elevated CO_2 increased the amount of dry matter and starch with decrease in glycoalkaloid and nitrates, improving the quality of tubers (Schapendonk et al. 2000; Donnelly et al. 2001; Vorne et al. 2002). Nearly all the nutrient elements tend to decrease in tubers under elevated CO_2 (Cao and Tibbitts 1997; Fangmeier et al. 2002) so also the citric acid content causing a higher risk of discoloration after cooking (Vorne et al. 2002).

12.3 Indirect Effects of Climate Change and Global Warming

12.3.1 Drought

Optimal water supply is essential for potato because of its shallow root system. The potato plant generally roots rather shallowly, 40–50 cm (Beukema and Van der Zaag 1990). Potato is extremely sensitive to drought particularly at tuber initiation with substantial loss in tuber yield. Dry matter partitioning to root, shoot, leaf, and stem as a function of development stage (DS) and the root: shoot ratio is affected by drought stress. Drought, while reducing dry matter production increases the root: shoot ratio indicating a shift in the balance of growth in favour of roots. Roots of plants grown in drought conditions also tend to be thinner. Both responses enable stressed plants to exploit the available soil moisture more effectively (Vos 1995). Tuber initiation and maturity under drought stress conditions is hastened (Beukema and Van der Zaag 1990).

12.4 Regional Vulnerability to Climate Change in India

The entire Indo-Gangetic plains, where irrigated potato is mainly grown, are vulnerable. However, the state of West Bengal with highest productivity and second largest potato-producing state in India appears highly vulnerable. Winters are mild in West Bengal, and ‘window’ of suitable growing period is small; any rise in temperature will severely impact productivity with associated problems of storage and post harvest handling of produce in warmer conditions. Other vulnerable states are Bihar and Uttar Pradesh, which contributes maximum in total potato production. The states of Punjab, Haryana, and adjoining areas in northern Rajasthan and Western Uttar Pradesh, where winters are relatively severe, experiencing occasional frost might benefit from global warming to certain extent. The rainfed crop in plateau regions and other areas in south India would be most vulnerable due to warming and associated drought conditions.

12.5 Observations on Aberrant Weather and Extreme Events

- Rains in winter season received at planting affects emergence and delays planting with reduction in tuber yield.
- Heavy showers during the crops season resulting in flooding affects tuber yield.
- Heavy rains at the time of harvesting induce rotting in field and in temporary heaps of harvested potato in the field.
- Overcast sky and rains early in the crop season invariably increases the attack of late blight disease with severe reduction in yield.
- Relatively warmer winters in the year 2008 reduced tuber yield in West Bengal, Uttar Pradesh, and Bihar.

12.6 Adaptation Measures for Climate Change and Global Warming

- Use of crop residue mulches for some period after planting.
- Using drip irrigation in place of furrow and basin methods.
- Alter cultural management in potato-based cropping systems.
- Conservation tillage and on farm crop residue management.
- Improvement and augmentation of cold storage facilities and air-conditioned transportation from production to consumption centres.
- Subsidizing additional cost of pests and water management.
- Insurance against weather for the cash crop of potato with high cost of cultivation.
- Strengthen education, research, and development in warm climate production technology for ware and seed potato crop.
- Alteration in planting date and integrated pest management (IPM).

12.7 Future Strategies for Research

- Quantification of regional vulnerability and impact assessment
- Development of early warning disease-forecasting systems
- Breeding short duration and heat-tolerant cultivars. Mining biodiversity to heat tolerance on priority

- Breeding drought, salinity-tolerant, and disease-resistant cultivars
- Advance planning for possible relocation and identification of new areas for potato cultivation
- Improved agronomic management for water and fertilizer use efficiency
- Development of agro-techniques for warm weather cultivation and potato-based cropping systems
- Development of virus and late blight resistant varieties
- Rescheduling of chemical sprays based on new emerging pathogen population
- Development of IPM strategies.

12.8 Conclusion

Potato a native of temperate region grown under long-day conditions in mild and cool summer season in Europe and America was introduced and adapted to tropical short-day conditions in India during the last century. The crop is mainly confined to Indo-Gangetic plains in mild and cool winters in India. The autumn/winter planted crop in northern plains of India comprising the states of Uttar Pradesh, West Bengal, Bihar, Punjab, and Haryana, contributes 84% of total potato production in India, where the crop is grown totally under irrigated conditions. Growth and development is affected at high temperatures encountered in the tropics. Although photosynthesis in potato is suppressed by high temperature, it is not as sensitive to temperature as tuberization and partitioning of photosynthates to tubers.

The elevated CO_2 will probably have little direct effect on most pathogens, as many soil-inhabiting fungi can tolerate more than 10- or 20-fold increases in CO_2. However, the impact of increased CO_2 concentrations on plant diseases is likely to be through changes in host physiology and anatomy. Global warming is likely to increase the incidence of viral, late blight, charcoal rot, and bacterial wilt and has little effect on early blight and may decrease wart, powdery scab, black scurf, and common scab diseases in Indo-Gangetic plains. Sudden outbreak of leaf hopper burn in Gujarat during 2006–2007, late blight in severe epiphytotic form in Karnataka and Maharashtra during 2006–2007 and 2008, and apical leaf curl virus infestation in Indo-Gangetic plains are the reminders of climate change and its adverse effect on potato crop. The insect pest and vector biology are expected to change dramatically with increase in temperature.

The climate change and global warming will have a profound effect on potato growth story in India, impacting every aspect of not only production and profitability but seed multiplication, storage, marketing, and processing of this perishable vegetatively propagated crop. Under the impact of future scenarios of climate change, the growth projections of potato in India might be arrested or even reversed, unless effective adaptation measures are evolved for timely application and implementation. Increase in temperature and atmospheric CO_2 are interlinked occurring simultaneously under future climate change and global warming scenarios. Effect of their interaction on potato would be more relevant and of greater economic significance compared to their usually counteracting direct effects on crop growth, yield, and quality. It is estimated that due to global warming, potato production in India may decline by 3.16% and 13.72% from current levels by the year 2020 and 2050, respectively. The potato production will be directly affected by climate change, while there would be several indirect effects on various facets of supply, storage, utilization, and acreage of the crop in future climate scenarios. It is imperative that the weather/climate changes are monitored on regular basis along with disease and insect pest infestation.

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13

Adaptation Options for Sustainable Production of Cucurbitaceous Vegetable Under Climate Change Situation

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Abstract

Cucurbits are vegetable crops belonging to the family Cucurbitaceae. The family consists of about 118 genera and 825 species. These crops are important sources of livelihood securities for resource poor farmers and can be grown in varied agroclimates ranging from temperate, subtropical, tropical, and arid deserts. Recently, cultivation of crops including cucurbits is confronted with biotic and abiotic stresses caused by global climate change. It is argued that increased CO_2 concentration has beneficial effect on productivities of several crops when studied in isolation. However, under field conditions, the interaction between CO_2 concentration and increased temperature needs to be investigated in details. Pressure of biotic stresses is also likely to increase due to climate change. Wild relatives of cucurbits are also equally impacted by rise in temperatures. It is feared that important species of many crops possessing valuable gene pools will be on the verge of extinction in the near future. The grave ramifications of climate change can be circumvented with a combination of effective climate protection and adaptation measures. Climate protection measures are well established in the Kyoto Protocol to the UN Framework Convention on Climate Change. Possible adaptation measures for cucurbits are weather forecasts, simulation models, breeding short duration varieties, breeding heat- and drought-tolerant varieties, and agronomic manipulations. Developing stress-tolerant/stress-avoiding varieties and appropriate production technologies in cucurbits have a great potential to contribute to food and livelihood security in vulnerable agricultural environments.

13.1 Introduction

Cucurbits are vegetable crops belonging to family Cucurbitaceae. The family consists of about 118 genera and 825 species. There is tremendous genetic diversity within the family, and the range of adaptation for cucurbit species includes

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tropical and subtropical regions, arid deserts, and temperate regions. Cucurbits are consumed in various forms, *i.e*., salad (cucumber, gherkins, long melon), sweet (ash gourd, pointed gourd), pickles (gherkins), deserts (melons), and culinary purpose. Some of them, e.g., bitter gourd, are well known for their unique medicinal properties. In recent years, abortifacient proteins with ribosome-inhibiting properties have been isolated from several cucurbit species, which include momordicin (from *Momordica charantia*), trichosanthin (from *Trichosanthes kirilowii*), and beta-trichosanthin (from *Trichosanthes cucumeroides*). In India, a number of major and minor cucurbits are cultivated in several commercial cropping systems and also as popular kitchen garden crops. Cucurbits share about 5.6% of the total vegetable production in India. Cucurbits are cultivated in all parts of India under varied agroclimatic conditions. Like other crops, cucurbits are also sensitive to climate change and various abiotic stresses.

13.2 Possible Impact of Climate Change on Agriculture Including Vegetables

Despite technological advances like improved varieties, fertilizers, irrigation systems, and biotechnology, weather is still the key determining factor for agricultural productivity. The possible impacts of climate change on agriculture including vegetables are given below.

1. Increase in temperature increases transpiration and in drier regions leads to water stress causing yield reduction. In India, only about 41% area is irrigated and remaining 59% is rainfed. Even if we realize full irrigation potential in the country, nearly 50% area will still remain rainfed. Under such circumstances, increase in temperatures and changes in rainfall patterns are likely to reduce agricultural productivity in rainfed areas.
2. The changed climate will probably lead to a decrease in crop productivity, but with important regional differences (McCarty et al. 2001). In tropical and subtropical regions like in India where the crops are already near the limit of their temperature tolerance, even a slight increase in temperature will result in drastic fall in crop productivity. However, crop productivity is expected to rise slightly in mid-to high latitudes for mean temperature increases of up to 3°C. Coupled with enhanced CO_2 concentration, food productivity in these areas is expected to rise with rise in temperature up to 3°C and fall with further rise in temperature.
3. High temperature increases the rate of development in plants. A short life cycle, though less productive, can be beneficial for escaping drought and frost and late maturing cultivars could benefit from faster development rate. In colder regions, global warming could lead to longer of growth period and optimal assimilation at elevated temperatures.
4. Droughts, floods, tropical cyclones, heavy precipitation, and heat waves will negatively impact agricultural production.
5. Due to melting of glaciers, global sea levels are likely to rise from anywhere between 180 and 590 mm by end of this century leading to loss of land, coastal erosion, flooding, and salinization of ground water. Rapid melting of glaciers in Himalayas could affect availability of water for irrigation especially in the Indo-Gangetic plains as well as neighboring countries.
6. The current fertilizer-use efficiency that ranges between 2% and 50% in India is likely to be reduced further with increasing temperatures. Greater fertilizer use to boost agricultural production will in turn lead to higher emission of greenhouse gases.
7. Small changes in temperature and rainfall will have significant impact on quality of fruits and vegetables with resultant implications in domestic and external trade.
8. Changes in temperature and humidity will also change pest (diseases and insects) population. New and aggressive pests including weeds are likely to invade our crops.

13.3 Adaptation Strategies for Cucurbitaceous Vegetables

Farmers in developing countries including India need adaptive tools to manage the adverse effects of climate change on agricultural productivity and particularly on vegetable production and quality.

Adaptation involves the action that people take in response to or in anticipation of projected or actual changes in climate to reduce adverse impacts and also derive advantage from the opportunities posed by climate change (Parry et al. 2005). However, farmers in our country are usually small-holders and rely heavily on resources available in their farms or within their communities. Thus, technologies that are simple, affordable, and accessible must be developed to increase the resilience of Indian farms. Various management practices are available that have potential to grow vegetables successfully under hot and wet conditions of the lowland tropics. Potential impacts of climate change on agricultural production will depend not only on climate per se, but also on the internal dynamics of agricultural systems, including their ability to adapt to the changes (FAO 2001). Different strategies for climate change adaptation include development of resilient varieties, modifying fertilizer application to enhance nutrient availability to plants, direct delivery of water to roots (drip irrigation), grafting to increase flood and disease tolerance, and use of soil amendments to improve soil fertility and enhance nutrient uptake by plants. Some of the potential adaptive measures for cucurbitaceous vegetables are described below.

13.3.1 Development of Climate-Resilient Varieties

13.3.1.1 Breeding Strategies

Improved germplasm is the most cost-effective option for farmers to meet the challenges of a changing climate. While breeding for high yields, we have been counter selecting genotypes that are water and fertilizer responsive. Superior varieties adapted to a wider range of climatic conditions could result from the discovery of novel genetic variation for tolerance to different biotic and abiotic stresses. Genotypes with improved attributes conditioned by superior combinations of alleles at multiple loci could be identified and advanced. Improved selection techniques are needed to identify these superior genotypes and associated traits, especially from wild and related species that grow in environments which do not support the growth of improved high yielding varieties. Plants native to climates with marked seasonality are able to acclimatize more easily to variable environmental conditions and provide opportunities to identify genes or gene combinations which confer such resilience.

13.3.1.2 Development of Genotypes Resistant/Tolerant to Diseases and Insect Pests

Large gene pool is available in Cucurbitaceae family which can be utilized for the development of pest-tolerant/-resistant varieties or elite breeding lines in cucumber, muskmelon, watermelon, and other important cucurbitaceous vegetable crops. The resistant sources identified in important cucurbits are given Table 13.1.

13.3.1.3 Development of Genotypes Tolerant to Drought

Plants resist water or drought stress in many ways. In slowly developing water deficit, plants may escape drought stress by shortening their life cycle (Chaves and Oliveira 2004). However, the oxidative stress of rapid dehydration is very damaging to the photosynthetic processes, and the capacity for energy dissipation and metabolic protection against reactive oxygen species is the key to survival under drought conditions (Ort 2001; Chaves and Oliveira 2004). Tissue tolerance to severe dehydration is not common in crop plants but is found in species native to extremely dry environments (Ingram and Bartels 1996). Some *Cucurbita* sp. possess some xerophytic characters essential to adapt under water scarcity conditions. This gene pool should be thoroughly studied to isolate drought-tolerant lines in pumpkin and squash. Drought stress is a major environmental factor influencing plant growth and development. *Citrullus colocynthis* is highly drought-tolerant cucurbit species with a deep root system. Differences in gene expression during drought were studied using cDNA-AFLP. Two genes, CcrbohD and CcrbohF, encoding respiratory burst oxidase proteins were cloned using RACE. RT-PCR analysis showed that expression of CcrbohD was rapidly and strongly induced by abiotic stress imposed by PEG, ABA, SA, and JA treatment. CcrbohD has great promise for improving drought tolerance of other cucurbit species.

Table 13.1 Genetic resource in cucurbits resistant to different diseases and insect pests

Crop	Disease/insect pests	Resistance source	References
Cucumber	Powdery mildew	PI 197087, Poinestee, Yomaki, Sparton Salad, PI 197088, *Cucumis ficifolia*, *C. anguria*, *C. dinteri* and *C. sagittatus*, *C. ficifolia* accessions IVf 1801 and PI 280231, *C. anguria* PI 147065, *C. anguria* var. *anguria*, *C. dinteri* PI 374209, and *C. sagittatus* PI 282441	Barnes 1966, Imam and Morkes 1975, Omara 1979, Munger 1979, Lebeda 1984, Choudhary and Fageria 2002, Seshadri US 1990
Cucumber	Downy mildew	Chinese Long and Poinsette	Imam and Morkes 1975, Seshadri 1986, Lower and Edwards 1986
Cucumber	Anthracnose	PI 197087 and PI 175111	Barnes and Epps 1952, Hayja and Peterson 1978 Abul-Hayja et al. 1978, Abul-Hayja and Peterson 1978
Cucumber	CMV	TMG-1, Tokyo Long Green, Chinese Long, Wisconsin and Table Green	Provvidenti 1985, Provvidenti and Hampton 1992
Cucumber	CGMMV	*Cucumis anguria*	Den-Nij 1982
Cucumber	WMV	Table Green and Sarinam	Takeda and Gilbert 1975 & Provvidenti 1985
Musk melon	Powdery mildew	Edisto, PMR-45 and PMR-450; Georgia-47 and C-68; Campo and PMR-6; Arka Rajhans, RM-43 and Pusa Sharbati Campo, Jacumba, Levlita, PM-5 and PMR-6, PI 164323, and PI 180283	Copeland 1957, Bohn and Whitaker 1964, Takada et al. 1975, Norton and Cosper 1985, Choudhury and Sivakami 1972, Khan 1973
Musk melon	Downy mildew	Edisto, Seminole; Buduma Type –1, 2, and 3, Phoontee, Goomuk, Nakkadosa, Ex-2, Annamalai, Edisto, and Harvest Queen; *Cucumis callosus*, WMR-29, MR-1, Punjab Rasila, Cinco, DMDR-1 and DMDR-2; Punjab Rasila; EC 163888; Snapmelon collections like SP-1, SP-2, SP-3, KP-2, KP-7, and KP-9	Copeland 1957, Whitner 1960, Sambandam et al. 1979, Zink et al. 1983, Nandpuri 1993, Singh 1996
Musk melon	Fusarium wilt	Delicious-51 and *C. melo* var. *reticulatus*, *indorus*, *chito,* and *flexuosus*	Munger 1954 and Zink et al. 1983
Musk melon	Gummy stem blight	Line PI 140471	Norton and Cosper 1989
Musk melon	CMV	Freeman	Karachi 1975
Musk melon	WMV	PI 414723, B 66–5 and *C. metuliferus*	Webb and Bohn 1962, Webb 1979, Provvidenti and Robinson 1977
Musk melon	Zucchini yellow mosaic virus	PI 161375	Lecoq and Pitrat 1985
Watermelon	Powdery mildew, downy mildew, and anthracnose	Arka Manik	Nath 1973
Watermelon	Anthracnose	Black Stone, Charleston Gray, and Cargo	Robinson and Shail 1981 & Suvanjrakorn and Norton 1980

Watermelon	*Fusarium* wilt	Citron, Calhoun Gray, Sornkylee and Summit, Dixielle, All Sweet, Crimson Sweet, Charleston Gray, and Lousiana Queen	Orton 1911, Elmstrom and Hopkins 1981
Pumpkin and squash	Powdery mildew	*C. moschata*	Sowell and Corley 1969
Pumpkin and squash	Bacterial wilt	*C. pepo*, *C. maxima*, *C. andreana*, and *C. lundellina*	Watterson et al. 1971
Pumpkin and squash	Squash mosaic virus	*C. pepo*, *C. maxima*, and *C. moschata*	Salma and Sill 1968
Pumpkin and squash	WMV and CMV	*C. ecuadorensis* and *C. foetidissima* against	Provvidenti et al. 1978
Cucurbits	Two-spotted spider mite	Cucumber	Gould 1978
Cucurbits	Melon aphid, fruit fly, leaf miner, and red spider mite	Musk melon	Bohn et al. 1972, Khandelwal and Nath 1978, Dhooria et al, 1987

13.3.1.4 Development of Genotypes Tolerant to Salinity

Attempts to improve the salt tolerance of crops through conventional breeding programs have very limited success due to the genetic and physiologic complexity of this trait (Flowers 2004). In addition, tolerance to saline conditions is a developmentally regulated, stage-specific phenomenon; tolerance at one stage of plant development does not always correlate with tolerance at other stages (Foolad 2004). Success in breeding for salt tolerance requires effective screening methods, existence of genetic variability, and ability to transfer the genes to the species of interest. Screening for salt tolerance in the field is not a recommended practice because of the variable levels of salinity in field soils. Screening should be done in soil-less culture with nutrient solutions of known salt concentrations (Cuartero and Fernandez-Munoz 1999).

13.3.2 Strategies for Water Economy

13.3.2.1 Irrigation Methods

The quality and efficiency of water management determine the yield and quality of vegetable products. The optimum frequency and amount of applied water is a function of climatic and weather conditions, crop species, variety, stage of growth and rooting characteristics, soil water retention capacity and texture, irrigation system, and management factors (Phene et al. 1985). Too much or too little water causes abnormal plant growth, predisposes plants to infection by pathogens, and causes nutritional disorders. If water is scarce and supplies are erratic or variable, then timely irrigation and conservation of soil moisture reserves are the most important agronomic interventions to maintain yields during drought stress. There are several methods of applying irrigation water, and the choice depends on the crop, water availability, soil characteristics, and topography. Application of irrigation water could be through overhead, surface, drip, or subirrigation systems. Surface irrigation methods are utilized in more than 80% of the world's irrigated lands, yet its field level application efficiency is often 40–50% (Von Westarp and Chieng 2004). Drip irrigation delivers water directly to plants through small plastic tubes due to which water losses due to run off and percolation are minimized and water savings of 50–80% are achieved when compared to most traditional surface irrigation methods. Thus, more plants can be irrigated per unit of water by drip irrigation, and with less labor. In Nepal, cauliflower yields using low-cost drip irrigation were not significantly different from those achieved by hand watering; however, the long-term economic and labor benefits were greater using the low-cost drip irrigation (Von Westarp and Chieng 2004). The water-use efficiency in chili pepper was significantly higher in drip irrigation compared to furrow irrigation, with higher efficiencies observed in high delivery rate drip irrigation regimes (AVRDC 2005). For drought-tolerant crop like watermelon, yield differences between furrow and drip irrigated crops were not significantly different; however, the incidence of Fusarium wilt was reduced when a lower drip irrigation rate was used. In general, the use of low-cost drip irrigation is cost-effective and labor-saving and allows more plants to be grown per unit of water, thereby both saving water and increasing farmers' incomes at the same time.

13.3.2.2 Mulching

Various cultural practices such as mulching, the use of shelters, and raised beds are helpful for protection against high temperatures, heavy rains, and flooding. They also conserve soil health in terms of soil moisture and nutrient conservation required for crop production. The organic and inorganic mulches are commonly used for the production of high-valued cucurbitaceous vegetable crops, viz., gynoecious parthenocarpic cucumber hybrid, gynoecious bitter gourd, and summer squash, especially zucchini type either in open or in protected condition. These protective coverings help to reduce evaporation, moderate soil temperature, reduce soil runoff and erosion, protect fruits from direct contact with soil, and minimize weed growth. In addition, the use of organic materials as mulch can help to enhance soil fertility, structure and other soil properties. In India, mulching improved the growth of bottle gourd, round melon, ridge gourd, and sponge gourd compared to the non-mulched controls

Table 13.2 Resistant/tolerant root stocks for cucurbitaceous vegetable crops

Crop	Root stock	Description	References
Bottle Gourd	*Cucurbita moschata* (Duchesne ex. Pow) x *C. maxima* (Duchense ex. Lam.)	Highly resistant to the common pathovars of *F. oxisporum*	Trionfetti Nisini et al. 2002, AVRDC 2009
Cucumber	*L. siceraria*. *C. moschata*, and *Benincasa hispida* (Thunb.)	Resistance to *Phvtophthora capsici* Leonian and *F. oxvsporum*	Wang et al. 2004
Watermelon	*L. siceraria*. *C. moschata*, and *Benincasa hispida* (Thunb.)	Cucumber Mosaic Virus (CMV). Watermelon Mosaic Virus (WMV-11), Zucchini Yellows Mosaic Virus (PRSV). or Zucchini Yellows Mosaic Virus (ZYMV)	Wang et al. 2002
Cucumber	Fig leaf gourd (*Cucurbita ficifolia* Bouché) and bur cucumber (*Sicos angulatus* L.)	Low temperature tolerance	Tachibana 1982, Lee 1994, Ahn et al. 1999, Rivero et al. 2003
Cucumber	Squash rootstock (*Cucurbita moschata* Duch)	Suboptimal temperature tolerance	Shibuya et al. 2007
Watermelon	Shin-tosa-type (*Cucurbita maxima* × *C. moschata*)	Low temperature tolerance	Davis et al. 2008
Watermelon	*Cucurbita maxima* Duchesne × *Cucurbita moschata*	Water-deficit tolerance	Rouphael et al. 2008
Bitter melon	Luffa (*Luffa cylindrica* Roem cv. Cylinder-2)	Waterlogging tolerance	Liao and Lin 1996
Watermelon	*Lagenaria siceraria* cv. SKP a landrace	Waterlogging tolerance	Yetisir et al. 2006, Liao and Lin 1996
Musk melon	Hybrid squash	Salt tolerance	Romero et al. 1997
Cucumber	*Cucurbita* spp.	Tolerance to organic pollutants like drins	Otani and Seike 2007
Cucumber	*Cucurbita maxima* Duchesne × *Cucurbita moschata* Duchesne	Tolerance to organic Pollutants like drins	Otani and Seike 2007

(Pandita and Singh 1992). Yields were the highest when polythene and sarkanda (*Saccharum* spp. and *Canna* spp.) were used as mulching materials. Planting cucurbitaceous vegetables in raised beds can ameliorate the effects of flooding during the rainy season.

13.3.3 Grafting: Tool for Stress Tolerance Under Climate Change Situation

Grafting in fruit trees is normally used to circumvent the problems associated with soil born biotic and abiotic factors. In vegetables including cucurbits, certain root stocks have been identified which possesses tolerance/resistance against such stresses. Grafting on these resistant/tolerant root stocks protects the crop from ill effects of soil born stresses. Some of root stocks identified cucurbits are given in Table 13.2.

13.4 Conclusion

Vulnerability assessment is a key requirement to know the possible impact of climate change and implement adaptation strategies and policies. Several tools have been developed for vulnerability assessment. The important ones are Community-based Risk Screening Tool-Adaptation and Livelihoods (CRiSTAL) developed by the International Institute for Sustainable Development and Assessment and Design for Adaptation to Climate Change: a Prototype Tool (ADAPT) developed by the World Bank. These models screen multiple regions, multiple sectors (agriculture, irrigation, biodiversity, infrastructure, etc.), reveal region-wise risks of climate change, and suggest options for adaptation.

To circumvent losses due to climate change, adaptation measures are essential in affected areas. Some of the possible adaptations for cucurbits under low to moderate climate change are given below.

1. Early warning through value-added weather forecast systems is one of the most important components of adaptation measures. Forecasts on rains, storms, pest appearance, etc., would be highly useful to the farmers to schedule their activities.
2. Breeding new varieties having tolerance to water stress and high temperatures are the best options to fight climate change.
3. Short-season varieties due to their shorter vegetative periods can avoid unfavorable conditions.
4. Adaptation to changed climatic conditions is also possible by adjusting planting dates. In some areas with intense weather change, this may lead to shifting of cropping seasons.
5. Growing mixed varieties and intercropping are likely to reduce vulnerability of a field to climate change as well as incidence of pests.
6. Mulching is helpful in many ways like raising organic content of the soil, improving water holding capacity, reducing runoff and erosion, and making more water available for plants.
7. Micro-irrigation systems like drip irrigation can improve water-use efficiency, reduce fertilizer requirement, and improve productivity as well as quality.

Under severe climatic changes, the farmers are left with only two options, viz., abandonment cultivation of cucurbits or shifting in new areas where these can be grown economically.

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Phenotyping Horticultural Crops for Abiotic Stress Tolerance

14

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Abstract

Plants' growth and development is dependent on the environmental conditions, and they require optimum conditions not only at critical phenological stages but during the entire growth cycle. Crops must be grown in optimum environmental conditions to attain highest genetic yield potential, which is seldom attained due to occurrence of abiotic stresses at critical stages in field conditions. The adverse impacts of abiotic stresses have always challenged the farmers and scientists alike to devise adaptation strategies to overcome adverse impacts and sustain productivity. Plants, through constant and complex interaction between genotype and environment, have developed inherent ability to survive adverse environmental conditions. To unravel this, extensive efforts have been made to characterize crop plants through screening for abiotic stress tolerance and elucidate the biochemical and physiological mechanisms imparting such tolerance. Modern biology has attempted to understand how genotypes manifest to specific phenotypic characteristics, and efforts are also underway in development of cultivars with useful characteristics. The assessment of phenotype from genotype of a plant poses many difficulties due to contribution of large number of genes to the plant's phenotype under various environmental conditions. However, the concerted efforts by scientists have enabled to identify traits for large-scale screening of germplasm both under controlled and field conditions. Plant phenotyping requires the availability of a diverse germplasm, and the simulation of a target environment that crop is expected to experience under field conditions. The simulated environment needs to be dynamic or constant depending on the need. Temporal and spatial changes during the crop growth also need to be kept

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in mind. Ultimately, the phenotyping efforts need to comprehensively encompass the traits desired to overcome the adverse effects of abiotic stresses under field conditions. Now, phenotyping has been taken to new level using high-throughput phenotyping combining imaging and information technologies. The phenotyping options available for abiotic stress tolerance for horticultural crops are discussed here.

14.1 Introduction

Plants have adapted to different agro-ecological regions, and their growth and development is dependent on the growing environmental conditions. Plants require optimum environmental conditions not only during the critical phenological stages but also throughout the entire growing period. To attain the highest genetic yield potential, a crop must be grown in an environment that meets the optimum conditions. Even though the crops are well adapted to a particular agro-ecological region, they seldom attain the genetic yield potential due to occurrence of abiotic stresses at sensitive stages (Fitter and Hay 2002). Though the crops can be grown with minimal adjustments under such circumstances, the unfavourable environmental conditions at critical stages of crop growth lead to lower yields. Since horticultural crops are both annual and perennial in nature, the abiotic stresses impact them differently when compared to agriculture crops. Additionally, the impacts of climate change and climate variability are projected to steadily manifest directly from the frequency and intensity of droughts, floods and high-temperature episodes. Climate change is expected to result in long-term water shortages, droughts, worsening soil conditions and high-temperature extremes during the cropping season (IPCC 2007). Such adverse impacts during the sensitive stages of crop growth have always challenged the farmers and scientists alike to devise adaptation strategies to overcome adverse impacts and sustain productivity.

Diverse agro-climatic conditions available in India provide ample opportunity to grow a variety of horticulture crops round the year, placing India as the world's second largest producer of fruits and vegetables after China (Indian Horticulture Data base 2010). Horticulture is a high-priority sector of agriculture where impacts of climate change will have profound implications on the livelihood and nutritional security. Though some spices and plantations are location specific, horticulture crops like fruits, vegetables, flowers, medicinal plants and tubers are grown in diverse climates from tropical to temperate conditions. In order to sustain horticultural production with challenges of climate change and climate variability, we need to develop strategies to manage abiotic stresses. The strategy needs two pronged approach, one developing superior tolerant cultivars and another developing suitable cultural practices to manage abiotic stresses occurring at critical stages of crop growth and development. Though resorting to adaptations through cultural practices provides immediate relief from abiotic stresses, developing superior tolerant cultivars is a long-term approach. Adapting such an approach needs thorough phenotyping of the available germplasm for tolerance to abiotic stresses and consequently identifying tolerance traits and most suitable genotypes.

Modern biology has been putting in enormous efforts to understand how genotypes manifest to specific phenotypic characteristics. The efforts are also underway in the development of cultivars with useful characteristics. The assessment of phenotype from genotype of a plant poses many difficulties due to contribution of large number of genes to the plant's phenotype under various environmental conditions. Plant phenotyping helps in description of the processes involved and assessment of the phenotypes that could have the desirable traits. Plant physiologists are facing the need to quantify individual phenotypes that correspondingly match the individual genotypes.

The critical stage for measuring the phenotypic traits is very important because at critical stage, correlation between the trait and final yield is the highest. The efforts in the direction of phenotyping and consequent genetic enhancement need to be oriented in identifying the critical stage at which variability in the target traits plays an important role. This approach helps in making the critical stage more diagnostic for a particular trait. We need to further consider the variability in the target traits during the complete growth cycle of the plant.

Extensive efforts have been made to characterize crop plants through screening for physiological and biochemical mechanisms adopted by plants to tolerate abiotic stresses (Rahman et al. 2004; Aazami et al. 2010; Bananuka et al. 1999). The large-scale screening of germplasm using certain traits has also been attempted in many crops both under controlled and field conditions. Further, phenotyping has been taken to new level of high-throughput phenotyping combining imaging and information technologies. In this chapter, the attempts made by several scientists to characterize, and phenotype horticultural crops for abiotic stress tolerance are discussed.

14.2 Evaluation for Physiological and Biochemical Mechanisms

Plants, through constant and complex interaction between genotype and environment, have developed inherent ability to survive adverse environmental conditions. The response to abiotic stresses is a complex phenomenon, because it involves simultaneous responses at whole-plant, organ, cellular and molecular levels. Overall, the plants respond through complex intracellular signalling cascades that regulate biochemical and physiological acclimation. Thus, the outcome of constant interaction of genotype and the environment is the plant's phenotype. The phenotype could be considered as a multi-scale description of an organism's attributes displayed in space through time. It is expressed at various organizational levels, from molecules to metabolic networks to cell development and physiological processes, finally integrating into the yield-determining characteristics. Thus, the expression of plant's phenotype becomes dynamic under the influence of environmental variables.

An understanding of physiological and biochemical events associated with abiotic stresses is essential for enhancing the tolerance of the future cultivars. Considerable progress has been made to elucidate plants' physiological and biochemical mechanisms that enable them to tolerate abiotic stresses (Chaves et al. 2003; Chaves and Oliveira 2004; Chandrashekar et al. 2012). The techniques have been mainly employed to identify the differences in metabolism and physiological processes and traits imparting tolerance. Thus, studies have deciphered the role of such mechanisms imparting tolerance. The efforts directed primarily to screen genotypes for tolerance to abiotic stresses in target environments, both in controlled and field conditions, have helped physiologists in exploring the diversity among germplasm for tolerance traits. This understanding has further helped plant breeders in developing cultivars possessing tolerant to abiotic stresses.

The traits like gas exchange characteristics have been observed being influenced by abiotic stresses and are higher in the tolerant cultivars compared to the susceptible ones (Grzesiak et al. 1999; Ekanayake et al. 1998; Zhang Jie1 et al. 2012); differences in intrinsic water-use efficiency (Pimentel et al. 1999; Condon et al. 2002), a measurement dependent on gas exchange characteristics, have also been observed in Phaseolus vulgaris. Screening of tomato germplasm for root traits has shown the drought-resistant mutant derivatives showed significantly superior root characters. The root length, feeder root per 5 cm, tertiary root and root fresh weight were of primary importance and were strongly and positively associated with drought resistance (Kulkarni and Deshpande 2007). In bean plant, differences in water relations under water stress have been observed (El Tohamy et al. 1999). Hormonal regulations like ABA being the central regulator of plant responses to environmental stresses (Cramer 2010) and the changes in ABA were higher in the tolerant pea cultivar (Upreti and Murti 1999). Other subcellular processes such as photo-protective mechanisms including antioxidant systems have been studied (Reddy et al. 2004). In banana, higher ascorbate peroxidase and superoxide dismutase activities were associated with greater protection against water stress-induced oxidative injury (Chai et al. 2005); the regulation of water flow via aquaporins (Bramley et al. 2007) and signalling through abscisic acid help in coordination of abiotic stress tolerance processes (Shinozaki and Yamaguchi-Shinozaki 2007). Ultimately, phenotyping efforts should address the issues of yield through the evaluation in target environment.

Much progress has been made in identification and characterization of the mechanisms that impart tolerance to abiotic stresses. Plants respond to these abiotic stresses partly by activating the expression of stress-responsive genes, whose products are responsible for increasing the plant's tolerance (Kahn et al. 1993; Ravishankar et al. 2011). The understanding of how stress-responsive genes are activated by abiotic stress will help us to breed or engineer stress-tolerant crop plants. With the availability of complete information on a couple of plant genomes and of various genomics and proteomics tools, knowledge on plant abiotic stress responses has advanced at a great pace in the last few years. However, utilization of genomic information for crop improvement aimed at tolerance to abiotic stresses is severely constrained by lack of a one-to-one correspondence between phenotypes and genotypes. Though scientists have evolved techniques and procedures to evaluate plants for abiotic stress tolerance, there is a dearth of phenotyping procedures that are accurate and reproducible. Therefore, to bridge the gap, concerted efforts towards fine phenotyping for abiotic stress responses should be one of the major areas to focus upon. Now, plant phenotyping is a major field of research, and establishing robust protocols and screening methods is the need of the hour. Here the available germplasm of a crop of our interest is used to unravel the traits imparting tolerance to abiotic stresses, and this has been possible due to the advances in molecular technologies like sequencing. The genotypes having tolerance traits could be further subjected to molecular characterization, identification of candidate genes (Cocuron et al. 2007) and proteomics analysis (Schilmiller et al. 2010) and construction of metabolic or regulatory networks.

14.3 Need for Target Environments

The diverse germplasm of the crop of our interest needs thorough evaluation in the target environments to identify traits responsible for enhanced performance under the imposed conditions. Target environmental conditions need to be simulated and monitored throughout the experimentation. Since phenotyping is the analysis of plant's quantitative traits expressed through the interaction of plant and its growing environmental conditions, simulated target environment under controlled conditions should match the conditions the crop normally experiences in field during its growth and development. Hence, simulated environment could be dynamic or constant depending on the need. In order to simulate dynamic target environments, the temporal and spatial changes need to be maintained under field conditions.

14.4 Evaluation Under Controlled Conditions

Although field phenotyping is the best option to select genotypes of our interest in the target environment for yield and its component, the phenotyping in controlled environment facilities is advantageous for imposing abiotic stresses uniformly, which is not possible in field conditions. The studies on influence of abiotic stress factors like excess or limited moisture stress, high temperature and salinity are conducted under controlled conditions. The controlled conditions under which plants are grown should be relevant to the conditions prevailing in the field (Izanloo et al. 2008). Evaluation under controlled conditions is advantageous in terms of collecting data at a particular stage when the genotypes being tested differ in durations to attain certain phenological stage. Growing plants in pots allows for strict control of water stress imposed on test genotypes and the homogeneity of stress severity; such control is seldom achieved under field conditions, particularly when genotypes under test differ in phenology and/or biomass.

Phenotyping becomes more complex when the target traits are quantitative in nature and when the environmental conditions influencing target trait vary during course of the day, for example, temperature, light intensity and soil water status. In such situations, the phenotype of the plant is dynamic, and it is better defined by a series of response curves to environmental stimuli (Hammer et al. 2004; Tardieu et al. 2003, 2005). This approach is again time consuming and requires a tight control of environmental conditions (Tuberosa 2011). In addition, the time of measurement and sample collection become more important for morpho-physiological traits that fluctuate widely during the circadian cycle. Identifying the most appropriate time for measurement and sample collection is very critical for traits like plant water status, ABA content, stomatal conductance, leaf rolling and leaf temperature. Though the most appropriate time could be identified, measurement of certain traits is time consuming in a large number of plants. Such instances introduce variations in the data proportional to the duration of data collection. Here, the traits that encompass variability hold greater potential to minimize or altogether eliminate the effects on trait expression due to time of the day. In controlled condition study at 35°C day and 27°C night temperature, high-temperature-tolerant tomato line from AVRDC CL-5915-206 DG 2-2-0 had significantly higher leaf area and total biomass compared to susceptible cv. Arka Saurabh. No fruit set was observed in Arka Saurabh, while 40% fruit set was observed in CL-5915-206 DG 2-2-0 (Srinivasa Rao 1996). Genetic variability for temperature tolerance could be studied by exposing the seedlings to induction temperature. The temperature induction response (TIR) technique (Kumar et al. 1999; Srikanthbabu et al. 2002) is used to identify genotypes tolerant to high temperature. In this technique, the seedlings are exposed to severe challenging temperatures and allowed to recover at room temperature. The surviving seedlings at the end of the recovery period are selected as thermotolerant. Here it is hypothesized that induction stress is a prerequisite for the optimum expression of stress-responsive genes that bring about the intrinsic differences in stress tolerance among the different germplasm lines that are the same in terms of other characteristics. This technique has been used in crops like tomato (Senthil-Kumar and Udaykumar 2004) and pea (Srikanthababu et al. 2002).

14.5 Evaluation Under Field Conditions

Ultimately, evaluation of crop plants for yield performance under particular abiotic stress needs to be done under field conditions. Field phenotyping helps to identify tolerance traits in the ultimate target environment and helps in evaluating many genotypes at a time. Unlike controlled growth conditions, in field evaluations, there are certain factors which impact the quality of the phenotypic data to be collected (Tuberosa 2011) listed the following factors to be evaluated carefully to ensure the collection of meaningful phenotypic data in field experiments under water-limiting conditions. The factors are the experimental design, heterogeneity of experimental conditions between and within experimental units, size of the experimental unit and number of replicates, number of sampled plants within each experimental unit and genotype-by-environment-by-management interaction. Though the field evaluations are conducted in the ultimate target environments during the cropping season, slight variability in the environmental conditions or crop management during the experimentation might influence the plant's phenotype. Thus, the variability caused by these factors must be kept to the minimum so as to collect quality phenotypic information. In field evaluation, techniques like measuring canopy spectral reflectance (Gutierrez et al. 2010) and screening under high-temperature stress (Hazra et al. 2009) and drought stress (Ashraf et al. 2005; Rahman et al. 1998) are employed. The phenotyping methodologies like line source irrigation, withholding irrigation to impose water stress (Rao and Bhatt 1992), imposition of salinity stress and conducting evaluation trials during high-temperature periods in the hotspot areas are a few techniques that are followed under field conditions.

14.6 Water-Use Efficiency (WUE) as a Trait

Water is the major component of most horticultural crops as they are sold by fresh weight; thus, there is a necessity to maintain optimum water content of horticultural produce. The water available for agriculture in general and horticultural production in particular is at stake due to the increasing demand for fresh water for domestic consumption. Moreover, the increase in global average temperatures is likely to change the precipitation patterns and intensity resulting in water scarcity. Under climate change conditions, availability and quality of water will create bigger challenges (IPCC 2008). Such climate uncertainties create the need for efficient use of available water resources. Thus, the knowledge of traits contributing for better performance of crop plants under water stress conditions need to be enhanced. As we face the challenges of sustaining productivity even under the water-limiting conditions, traits like water-use efficiency (WUE) become more important. WUE is the amount of dry matter produced to the amount of water used by the plant through evapotranspiration. Hence, it involves the physiological processes that influence both dry matter accumulation and water use by the plant.

Although management techniques are playing an important role in enhancing water use and WUE in horticultural crops, there is a need to complement these efforts by improving WUE at the whole-plant level. This has become an important component of limited water stress resistance breeding. Selecting genotypes having high WUE alone may not be rewarding, as it may be associated with low biomass. Hence, selecting genotypes with high biomass potential and with high WUE under a stress environment may be more appropriate. Understanding the mechanism enabling root growth in a water-deficit environment and linking it with molecular markers may help to select this trait in segregating populations. Hence, a multidisciplinary approach, in pyramiding traits imparting drought tolerance while retaining the productivity potential of a genotype under irrigated environment, is desirable. The gravimetric approach for quantifying the water use and water-use efficiency of the test plants is very laborious and time consuming. Hence, scientists have depended on the surrogate methods of assaying the WUE.

Measurement of carbon-isotope discrimination (CID) as an indicator of transpiration efficiency is being used as a ‘surrogate’ measurement in crop physiology and plant breeding (Richards et al. 2010). Plants discriminate against the heavy isotope of carbon (^{13}C) naturally present in atmospheric CO_2, both in the process of CO_2 diffusion into the leaf and also in the metabolic processes of photosynthesis (Condon et al. 2004). This isotopic discrimination is reflected in the isotopic signature of plant dry matter. In C_3 crops, CID values are strongly related to stomatal conductance and transpiration efficiency for a given photosynthetic capacity (Condon et al. 2004; Richards et al. 2010). CID technique has proven to be a useful research tool to evaluate the genetic variation in transpiration efficiency of the available diverse germplasm and further breed the commercial varieties with greater water-use efficiency and yield. This technique involves the collection of samples at the end of the growing season and quantification of isotopic composition that reflects the overall effect of the entire growing season. Since this technique helps in avoiding collection of multiple samples at different phenological stages, it would be possible to phenotype large number of germplasm with limited number of plants. The study on tomato suggested that WUE can be increased by selecting low-carbon-isotope discrimination, but selecting low-carbon-isotope discrimination alone may identify a subpopulation of small plants (Martin et al. 1999). In grapes, carbon-isotope discrimination (Δ) of laminae dry matter ranged from 20.8% to

22.7%, and there was a negative relationship between transpiration efficiency and carbon-isotope discrimination. A large proportion of variation in transpiration efficiency could be attributed to variation in stomatal conductance. Genotypic variation in photosynthetic capacity was also an important component of variation in transpiration efficiency (Gibberd et al. 2001).

14.7 Canopy Temperature Depression (CTD)

Canopy temperature depression measurement technique indicates the overall plant water status in terms of amount of water extracted from the rhizosphere and water lost from the canopy through evapotranspiration. Thus, this technique provides information on the rhizospheric size, depth and functionality in accessing soil moisture. It can be used as a fast, inexpensive screening tool of root features (Blum et al. 1982). Again in this technique, timing of measurements of canopy temperature differences between treatments is a critical factor. In field, even well-watered healthy plants, under conditions of high evapotranspirative demand, may shut their stomata before noon. This becomes relevant when different genotypes are evaluated for their capacity in resorting to water loss avoidance strategy. In this case, the timing of measurements to bring in good discrimination among genotypes needs to be determined for specific conditions. As the water stress progresses through the day, considerable readjustment during subsequent samplings is needed. An additional factor to be considered when measuring canopy temperature is the effect of leaf wilting, folding or rolling under stress (Grant et al. 2006, 2007; Leinonen et al. 2006). The plant canopy architecture will influence leaf temperature not only through the angle of leaves to the light source but also through the degree of self-shading in the canopy (Zheng et al. 2008). To a certain extent, the influence of self-shading can be reduced if the most suitable view angle is used, although different opinions have been expressed in this regard (Grant et al. 2006).

14.8 Need for Comprehensive Phenotyping

The ultimate goal of phenotyping is to reduce the genotype–phenotype gap, especially for quantitative traits. Keeping a good record of meteorological parameters like rainfall, temperatures, wind, evapotranspiration and light intensity allows for more meaningful interpretation of the results and identification of the environmental factors limiting yield (Sadras 2002). It also involves diverse genetic material, accuracy and precision of measurements and experimental conditions that represent target environment. For a number of traits such as stomatal conductance and flow of xylem sap measured with mechanical or electronic devices, accuracy and precision in measurements require calibration of the instrument prior to data collection. Presently, phenotyping techniques employed by physiologists resort to destructive sampling at critical stages. The field phenotyping approach involves measurements that are highly laborious, expensive and time consuming. The techniques involving manual measurements where each variable is measured separately do not allow the season long monitoring of complex traits. Such inherent problems faced in field phenotyping have led to application of remote sensing technologies.

Hence, the need for a comprehensive phenotyping, which captures the minute phenotypic differences among the genotypes, is being addressed through phenomics. It is an area of science employed to characterize phenotype of a plant in a more rigorous and highly efficient way and ultimately relate these phenotypic traits to the associated genes. Phenomics could be described as simply ‘high-throughput plant physiology’ (Furbank and Tester 2011). Thus, the phenotypic parameters could comprise morphological parameters from cell size to plant height and yield on one hand and molecular characterizations like fingerprints and transcript profiles on the other. Phenomics deals with large-scale collection of phenotypic data and its analysis. Though the traditional approaches of phenotyping were employed earlier to screen the available germplasm, this approach is distinguished by its scale and scope. It employs large populations of germplasm with an aim to identify genetic variations. Thus, the individual genotypes are screened for desirable traits with accuracy and throughput. The phenomics approach subject's plant to target growing conditions under which the traits are phenotyped and plants are closely monitored throughout the testing period. The process involves collection of data on the phenotype and experimental conditions in formats that could be analysed in detail.

The recent developments in plant phenomics as an emerging field have led to development of technologies to characterize plant performance and dynamics of plant structures and functions. The approach involves achieving high-throughput and high-content information using appropriate experimental designs. This involves simultaneous development of novel technologies of sensors and algorithms for automation of analyses. Thus, phenomics has developed into a scientific field that aims to accurately quantify phenotypic traits as a measure of plant performance. It involves multidisciplinary approach with studies at cellular, leaf and whole plant and further from crop to canopy. The plant phenomics would provide a comprehensive and continuous analysis of plant growth and performance employing new technologies. The phenomics facilities provide non-destructive and destructive measurements of above and belowground plant parts during the course of plant life cycle. Through the measurements of changes in leaf size, leaf temperature and plant growth over time, plant phenotyping helps in identifying tolerant genotypes from the diverse genetic pool available in both cultivated and wild relatives. An important role for these technologies in delineating next generation traits is 'reverse phenomics'. For example, for a phenotype that appears drought tolerant, understanding the basis for this trait, at the physiological and genetic level using high-resolution phenomics tools, provides us the knowledge base to find the next set of leads necessary to underpin progress in plant breeding.

Phenotyping can take place under laboratory, greenhouse or field conditions. Under laboratory conditions, environmental factors may be controlled and varied as desired and manipulating one or more factors in dedicated experiments. Through this controlled approach, the influence of specific genetic and chemical factors interacting with a limited number of environmental factors can be investigated. In contrast, field conditions are highly variable, fluctuating in time and space (Rascher and Nedbal 2006; Schurr et al. 2006; Mittler and Blumwald 2010). Despite this, new technologies capable of high-throughput phenotyping coupled with environmental monitoring at high spatial and temporal resolution can deliver data sets large enough for statistical approaches. For example, imaging spectroscopy can provide high-resolution pictures from ground and airborne platforms that contain high-resolution spectral data of millions of pixels (Rascher et al. 2009). Single spectra can be attributed to single plants or experimental plots and related to plant functional traits (Ustin and Gamon 2010). Growth and development of plants under abiotic stress conditions could be quantified through the measurement of biomass using cameras and image analysis. These analyses would ideally identify relationships between genotype and phenotype as well as reveal correlations between seemingly unrelated phenotypes (Schauer et al. 2006). High-throughput phenotyping platforms using the technique of imaging and image analysis are available for both laboratory and controlled greenhouse conditions (http://www.lemnatec.com/; http://www.plantaccelerator.org.au/). Phenomics is a large-scale approach to study how genetic information is translated into phenotypic traits of an organism. Latest phenotyping techniques using phenomics platforms through digital imaging could help in quantifying growth and development.

14.9 Plant Phenomics for Trait-Based Physiological Breeding

The complete analysis of quantifiable traits for physiological breeding requires the application of appropriate non-invasive techniques. Once important traits or 'yield components' contributing in a germplasm are identified, either a genomic region needs to be identified to select for this trait by marker-assisted selection (MAS) in breeding or, in the case of multigenic traits commonly encountered in quantitative physiological breeding, a robust phenotypic marker is pivotal (Furbank and Tester 2011). The biomass accumulation and growth of plant, being the ultimate expression of physiological processes, are currently being scored manually. Such traits could be captured through digital imaging. The phenomics tools can hasten the speed and the precision of measuring the traits of interest. These tools using digital imaging can obtain relatively simple properties of shape and texture as proxies for some traits. The aim of image analyses is to develop three-dimensional models throughout the duration of plant growth to enable collection of much detailed information. The tools enable us to collect specific information even to the level of what happens to each organ during the course of growth. The advantage of such direct measurement of the trait of interest through imaging is that it should be possible to exploit all the genetic variation responsible for a trait. For example, early seedling vigour, an important trait for conserving soil moisture, has been shown to be related to embryo size and is currently scored phenotypically by the width of the fully expanded leaves at young vegetative stage (Richards et al. 2010). Ultimately, the role of phenomics is to enable mapping genetic elements to biological function at detail.

14.10 Conclusion

Plant phenomics can, in fact, be considered as simply plant physiology in 'new clothes', but it promises to bring physiology up to speed with genomics by introducing the incredible recent advances made in computing, robotics and image analysis to the wider field of plant biology. A multidisciplinary team in plant phenomics crosses biology, physics and mathematics, not 'just' genetics, biochemistry, physiology and plant breeding. This trans-disciplinary approach promises significant new breakthroughs in plant science. Phenomics provides the opportunity to study previously unexplored areas of plant science, and it provides the opportunity to bring together genetics and physiology to reveal the molecular genetic basis of a wide range of previously intractable plant processes. The future challenges of characterizing crop plants for desirable traits require the advances we have seen in information technology, and there is a need to build on these advances for global food security. The better knowledge of the physiological, biochemical, molecular and genetic basis of the mechanisms promoting tolerance to abiotic stress will enhance the capacity to improve crop yield under hostile environments.

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Significance of Grafting in Improving Tolerance to Abiotic Stresses in Vegetable Crops Under Climate Change Scenario

15

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Abstract

Climate change world over is resulting in erratic rainfall and high- and low-temperature spells. The plant survival and food and nutritional security may be under threat because fruits and vegetable crops are found to be sensitive to environmental extremes such as the prevailing high and low temperatures and limited (drought) and excess soil moisture (flooding). The occurrence of extreme environmental or weather conditions influences the morphological, physiological, biochemical and molecular aspects of plant growth and development at all stages and also causes various types of physiological and pathological disorders in the plants. At cellular level, these stresses disrupt the cellular redox homeostasis which leads to the oxidative stress or generation of reactive oxygen species (ROS) which may sometimes cause cell injury and its death.

To meet the challenges of such extreme environmental conditions, different strategies were developed by the researchers and later on adopted by the farmers and agriculturists. One of the methods is to enhance or improve the genetic tolerance to such stresses by developing tolerant varieties. However, due to less genetic variability in relation to tolerance, breeding has remained a slow process in horticultural crops. In recent past, another significant method of adapting plants to counteract environmental stresses and improving the tolerance suggested by various researchers is changing the root system through grafting over selected vigorous rootstocks. Grafting is one of the promising tools for modifying the root system of the plant for enhancing its tolerance to various abiotic stresses. In present chapter, the importance of grafting in relation to different abiotic stresses has been discussed.

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15.1 Introduction

Projections of future impacts of climate change indicate that by 2020, the world may face greater risk of food shortage. The global temperature may increase by 3–4°C which may cause a serious threat to agricultural and horticultural production. Because of climate change, there is a strong possibility of frequent occurrence of abiotic stresses, which are major constraint worldwide to horticultural production in general and vegetable production in particular. Among the horticultural crops, vegetable crops are found to be more sensitive to environmental extremes such as the prevailing high and low temperatures, limited (drought) and excess soil moisture (flooding). Limited availability of arable land and high market demand for cucurbitaceous and solanaceous vegetables, they are frequently grown under unfavourable environmental conditions such as thermal stress, drought, flooding and persistence of organic pollutants in soil (Schwarz et al. 2010).

The climate change further magnifies the cause of low yields in temperate and tropical areas. In combination with high temperatures, decreased precipitation could cause reduction in availability of water and increase in evapotranspiration, leading to severe water-stress conditions (IPCC 2001). The occurrence of extreme environmental or weather conditions influences the morphological, physiological, biochemical and molecular aspects of crop growth and development at all the stages. These environmental stresses cause various types of physiological and pathological disorders in the plants. At cellular level, these stresses disrupt the cellular redox homeostasis which leads to the oxidative stress or generation of reactive oxygen species (ROS) (Asada 2006) in cell organelles such as mitochondria, chloroplast, peroxisome and nucleus resulting in cell injury and ultimately death of plant cells (Mano et al. 2008).

To meet the challenges of such extreme environmental conditions, different strategies were developed by the researchers and later on adopted by growers to cope up with these extreme environmental conditions. One of the methods is to enhance or improve the genetic tolerance to these stresses by developing tolerant varieties. This approach is being carried out under various breeding programmes. However, due to a lack of selection tools like genetic markers and also less genotypic variability in relation to tolerance to these conditions, it has remained a slow and time-taking process so far in horticultural crops. In recent past, another significant method of adapting plants to cope up with environmental stresses and improving the tolerance suggested by the researchers is changing the plant root system through grafting (Fig. 15.1) over selected vigorous rootstocks (Lee and Oda 2003; Dietmar et al. 2010). Grafting is nowadays considered as an efficient rapid alternative tool to the relatively slow breeding methodology aimed at enhancing environmental-stress tolerance of horticultural crops in general and vegetables in particular (Flores et al. 2010). It is considered to be a rapid tool of substantial and sustainable relevance (Rivard and Louws 2008). Though the concept of grafting vegetables originated in East Asia during the twentieth century to cope up with the soilborne diseases, presently it is a general practice in vegetable production in Asian countries such as Japan, Korea and some European countries.

15.2 Grafting in Vegetable Crops

In the beginning, grafting was adopted to reduce the effect of soilborne disease like Fusarium wilt (Scheffer 1957; Lee 1994; Ioannou 2001; Bletsos et al. 2003; Davis et al. 2008). However, at present, grafting is being used for improving yield (Bersi 2002; Kacjan-Marsic and Osvald 2004), enhancing nutrient uptake (Ruiz et al. 1997; Colla et al. 2010), increasing the synthesis of endogenous hormones (Proebsting et al. 1992; Dong et al. 2008), improving water use efficiency (Cohen and Naor 2002; Rouphael et al. 2008a), reducing uptake of pollutants from agricultural soils

Fig. 15.1 Grafted plants of tomato

(Otani and Seike 2006, 2007) and increasing the flowering and seed production (Lardizabal and Thompson 1990). Khah et al. (2006) reported that grafting can improve total yield of vegetables like tomato without having significant effect on quality of the fruits. In many cases, grafting was also used to alter hormonal production which in turn influences sex expression and flowering order of grafted plants (Satoh 1996).

In cucurbits such as watermelon, grafting over bottle gourd [*Lagenaria siceraria* (Mol.) Standl.] results in early formation of female flowers (Satoh 1996). However, in some cases like pumpkin (*Cucurbita maxima* Duchesne), bottle gourd, wax gourd [*Benincasa hispida* (Thunb.) Cogn.] and watermelon-grafted watermelon, especially in plants with 'Shintoza'-type rootstocks (*C. maxima* Duchesne × *C. moschata* Duchesne), flowering was delayed (Yamasaki et al. 1994). In addition to above-mentioned examples, workers have used grafting to improve quality of fruits (Fernández-García et al. 2004a, b, c; Colla et al. 2006), though there are contradicting views on this particular beneficial effect of grafting in vegetable crops. It was found that grafting also can limit the toxic effect caused by boron, copper, cadmium and manganese in many crops (Edelstein et al. 2005; Arao et al. 2008; Rouphael et al. 2008b; Savvas et al. 2009).

15.3 Significance of Grafting Under Environmental-Stress Conditions

Under the changing climatic conditions, various management practices have been adopted to improve the yield potential of horticultural crops under abiotic stresses such as hot and wet environmental conditions. The modification of fertilizer application to enhance nutrient availability to plants, providing direct supply of water to root system through drip irrigation and soil amendments to improve soil fertility and increasing efficient nutrient uptake by plants are some of the important adaptation strategies that the growers are following during the cultivation of horticultural crops. Grafting brings about a lot of changes in the plants where root system was changed. In vegetable crops, grafted plants are now being used to improve resistance against abiotic stresses like low and high temperatures (Bulder et al. 1990; Rivero et al. 2003c; Venema et al. 2008), drought, salinity and flooding (AVRDC 2000; Bhatt et al. 2002; Fernández-García et al. 2004a, b, c; Estan et al. 2005; Yetisir et al. 2006; Martinez-Rodriguez et al. 2008; He et al. 2009; Martínez-Ballesta et al. 2010). Because of these beneficial effects of grafting, the cultivation of grafted plants in crops like tomato, eggplant and pepper and cucurbits (melon, cucumber, watermelon and pumpkin) has increased in recent years (Lee and Oda 2003; Lee et al. 2010). Most of the reports on grafting suggest that scion is influenced by the rootstock by bringing about a change in uptake of water, minerals and plant hormones.

15.3.1 Temperature Stress

Temperature is one of the most significant environmental factors influencing the plant growth and development. The high and low temperatures cause heavy economic yield losses by reducing crop growth and its development, increasing disease incidence and affecting the reproductive growth by retarding the rate of truss appearance and fruit ripening in vegetable crop (Ahn et al. 1999). The occurrence of high and low temperatures causes the substantial damage to crop and crop yield as each aspect of growth, development, and/or fruit formation has its own optimum temperature requirement. In the present climate change scenario, there is irregular occurrence of high- and low-temperature spells which may affect these growth stages.

15.3.1.1 Low-Temperature Stress

Low soil temperature is one of the major factors influencing the plant survival causing heavy reduction in plant yield (Bradow 1990a, b), reducing plant growth and development and retarding fruit ripening (Reyes and Jennings 1994; Ahn et al. 1999). Each crop species has its temperature threshold for growth and development, for instance, the chilling-sensitive horticultural crops such as pepper, eggplant, cucumber, tomato and melon temperature threshold ranges between 8°C and 12°C (Hansen et al. 1994; Criddle et al. 1997). These crops may develop physiological disorders below the threshold temperature value and sometimes lead to plant death (Allen and Ort 2001; Venema et al. 2005) because of high sensitivity to low temperatures at both vegetative and reproductive stages (Jackman et al. 1988; Wang 1990).

The low temperature brings about morphological, physiological and biochemical changes in crop plants (Saltveit and Morris 1990). The response of crop to low temperature or suboptimal temperature depends upon on the period of exposure, the intensity of the low temperature and growth stage of the plant. Further, at each growth stage (vegetative, flowering and fruiting), plant respond differently. During vegetative growth of the plant, the low temperature mainly affects the leaf growth and development, its expansion, formation of new leaves and extension growth of the shoot. The reduction in leaf expansion and the formation of new leaves were not associated with a reduction in photosynthesis or the availability of photo assimilates (Venema et al. 2008) but attributed to the decrease in uptake of water and nutrient uptake. Some workers found that the low-temperature conditions cause water-stress-like condition (Choi et al. 1995; Ahn et al. 1999). In a crop like tomato, low or suboptimal temperature reduces fruit set due to poor pollen quality, increases the period between anthesis and fruit maturity and decreases appearance rate of truss (Van der Ploeg and Heuvelink 2005). Although low temperature negatively influences the root growth and development, much study has not been made on the root physiology in relation to low temperature.

Though efforts have been made in various breeding programmes to develop tolerant varieties, the genetic variability in relation to adaptability to low-temperature condition is very small in a crop like tomato (Van der Ploeg et al. 2007). Therefore, many workers regarded grafting of commercially grown plants over low-temperature-tolerant rootstocks as a promising tool for low-temperature tolerance (den Nijs 1980; Zijlstra et al. 1994; Rivero et al. 2003c; Venema et al. 2008). However, the performance of grafts under low-temperature conditions also depends upon the interaction between rootstock and scion, the physiological age of the graft combination and the duration and intensity of the low-temperature stress. In vegetable crops, certain rootstocks are found to be resistant to low-temperature conditions and thus may enhance the adaptive capability of scion.

The reason for causing resistance by these rootstocks is still not clearly understood. Some workers are of opinion that cold-tolerant rootstocks improve the water absorption by an increase of the root hydraulic conductance, decreased induction of cell wall suberin layers, lipid peroxidation and closure of the stomata under these conditions (Bloom et al. 2004; Lee et al. 2005) at chilling temperatures. However, Bloom et al. (2004) found that an increase in water uptake may be one of the important attributes in biomass partitioning to the roots as an adaptive mechanism under suboptimal temperatures. The low-temperature-sensitive plant species have an increase in superoxide, hydrogen peroxide (H_2O_2) and hydroxyl radicals, which may cause peroxidation of unsaturated membrane lipids (Tachibana 1982; Guy et al. 2008). In a crop like tomato, it was found that grafting can almost completely prevent the chill-induced accumulation of H_2O_2 in leaves (Rivero et al. 2003b). Many workers have found that low-temperature-tolerant rootstocks have a positive effect on photosynthesis under low root temperatures (Ahn et al. 1999; Zhou et al. 2007; Gao et al. 2008; Li et al. 2008; Miao et al. 2009). It was found that fig-leaf gourd (*Cucurbita ficifolia* Bouche) used as a rootstock improves the vegetative growth and yield of the plant at low-temperature condition (Zhou et al. 2007). In tomato, high-altitude growing rootstock accession LA1777 of *Solanum habrochaites* (synonym *Lycopersicon hirsutum* Dunal, Venema et al. 2008), KNVF (interspecific hybrid of *S. lycopersicum* × *S. habrochaites*, Okimura et al. 1986) and low-temperature-tolerant lines from backcrossed progeny of *S. habrochaites* LA 1778 × *S. lycopersicum* cv. T5 (Bloom et al. 2004) was found to enhance the tolerance of scion under low temperature.

Though efforts were made by various workers to select the vigorous rootstocks with tolerance to different abiotic stresses, there is still a need to identify the tolerant rootstock based on the physiological and biochemical markers and the physiological compatibility of rootstock with scion rather than adopting a causal approach in selecting the grafting as an abiotic stress alleviating tool. Tachibana (1988) found that the roots of squash plants under low temperatures stimulate meristem activity and photosynthate translocation. It was observed that cucumber (*Cucumis sativus* L.) grafted on *Cucurbita ficifolia* rootstocks and also on different genotypes of *Sicyos angulatus*, which are resistant to low temperatures, enhances growth and yield in the cucumber (Tachibana 1982; den Nijs 1984). In some of the species, the selection of rootstocks tolerant to low temperatures was made based on lipid differences in membranes (Horvath et al. 1980; Vigh et al. 1985). The application of grafting in alleviating the low-temperature effects needs further experimentation as the genetic variability for tolerance to low temperature is very less in crops like tomato.

15.3.1.2 High-Temperature Stress

The occurrence of high temperature influences the vegetable production in tropical and arid areas (Palada and Wu 2008; Abdelmageed and Gruda 2009). High temperature causes a significant alteration in morphological, physiological, biochemical and molecular response of the plant and in turn affects the plant growth, development and yield. The reduction in plant growth, decrease in photosynthesis rate and assimilate partition to reproductive organs (flower and fruits), increase in respiration, reduction in water and nutrient uptake, and increase in oxidative and osmotic damage are some of the important parameters affected by high temperature. High-temperature stress primarily affects the photosynthetic functions of higher plants (Weis and Berry 1988). In certain cases, high temperature activates the synthesis of special type of proteins called as heat shock proteins (HSP). High temperatures strongly reduce root elongation (Qin et al. 2007).

Generally, high-temperature condition causes a significant loss in productivity due to reduced fruit set and smaller and lower quality fruits (Stevens and Rudich 1978). The fruit set failure at high temperatures in tomato is attributed to bud drop, abnormal flower development, poor pollen production, dehiscence, viability, ovule abortion and poor viability, reduced carbohydrate availability and other reproductive abnormalities (Hazra et al. 2007). In bell pepper, high night temperature plays an important role in determining the plant growth in general and fruit set in particular (Bhatt and Srinivasa Rao 1993). The high pre-anthesis temperature condition also influences developmental changes in the anthers like irregularities in the epidermis and endothecium, lack of opening of the stomium and poor pollen formation (Sato et al. 2002). High postpollination temperatures inhibited fruit set, suggesting the sensitivity of fertilization to high-temperature stress in pepper (Erickson and Markhart 2002).

High day and night temperature influence fruit set in tomato (Berry and Uddin 1988). Though several breeding programmes have been made to improve the heat tolerance in crops sensitive to high-temperature conditions, the application of suitable cultural methods is needed to enhance tomato fruit set. There have been few studies on the effect of grafting on heat stress in crops like tomato. Grafting temperature-sensitive tomato onto more resistant rootstock cultivars improves plant adaptation to heat-stress conditions (Rivero et al. 2003a, b; Abdelmageed et al. 2004). In a study, Abadelhafeez et al. (1975) found that eggplants which are adapted to hot arid conditions have better temperature tolerance than tomato and contain efficient root system with respect to water uptake. It is reported that grafted plants found to develop better under heat-stress conditions than the ungrafted plants of tomato (Abdelmageed and Gruda 2009). The tomato plants grafted on eggplant have shown significantly higher value of chlorophyll florescence at late fruit stage, greater leaf area, leaf fresh weight and dry weight, number of pollen grains per flower and lower value of electrolyte leakage than ungrafted plants at 37/27°C. However, no positive effect was found on plant yield due to grafting. Therefore, there is a need of testing the better yielding plants as scion on strong root system rootstocks for improving the yield level under high-temperature conditions. Therefore, some workers have used eggplants as rootstocks for tomato at higher soil temperature and found it to be more promising (Abadelhafeez et al. 1975; Abdelmageed and Gruda 2009). According to Wang et al. (2007), the eggplants (*S. melongena* cv. Yuanqie) grafted onto a heat-tolerant rootstock (cv. Nianmaoquie) resulted in a 10% increase in fruit yield. Researchers at AVRDC have found higher yield in grafted plants of chilli under high-temperature conditions (Palada and Wu 2008). In a study, grafting tomato onto eggplants resulted in a reduction in electrolyte leakage under high-temperature stress, indicating less membrane damage and a higher ability to retain solutes and water (Abadelhafeez et al. 1975; Abdelmageed and Gruda 2009). Rivero et al. (2003a) have observed that grafted tomato over heat resistant rootstock (*L. esculentum* cv. RX.-335) had a reduction in H_2O_2 indicating lower oxidative stress. The studies of Rivero et al. (2003c) indicated that high temperature induces accumulation of phenolics in tomato plants by activating their biosynthesis as well as inhibiting their oxidation. However, in grafted plants, the impact of high-temperature stress was smaller than in ungrafted tomato plants, which shows that grafted plants have a higher degree of tolerance against thermal stress only when the rootstock is more thermal-stress tolerant. Grafted plants have also shown a massive accumulation of phenolic compounds, being correlated with greater biomass production and better development than ungrafted plants.

15.3.2 Water Stress

Since vegetable crops require assured irrigation for growth and development, the availability of water greatly influences the yield and quality of vegetable crops. However, the occurrence of limited (drought) and excess moisture (flooding) conditions drastically reduce crop productivity. Certain vegetable crops such as tomato, chilli and melons are sensitive to flooding and drought. The magnitude of the impact of these water stresses is determined by the timing, intensity and duration. During kharif season, production is often limited due to the occurrence of flash flood brought about by heavy rains.

15.3.2.1 Low Moisture Stress

Drought is perhaps the major factor limiting crop production worldwide (Jones and Corlett 1992). As a consequence of global climate changes and environmental pollution, water use for agriculture is reduced. The occurrence of erratic rainfall patterns creates drought condition. The global climatic change is expected to increase the water limitations in semiarid areas (IPCC 2001). In commercial crops like tomato and chilli, flowering and fruit enlargement stages were found to be highly sensitive to water stress. The occurrence of drought stress during these stages resulted in significant decrease in fruit number as well as fruit weight. In tomato, the number of flowering truss on plants was also significantly affected by drought. The drought condition induces flower abscission in tomato (Bhatt et al. 2009). More than 50% yield reduction was reported in tomato because of water stress during reproductive stage (Srinivasa Rao and Bhatt 1992). It has been suggested that water stress at flowering stage reduces photosynthesis and the amount of photosynthetic assimilates allocated to floral organs and might thereby increase the rate of abscission. Water stress may also cause an increase in ethylene biosynthesis (Elbeltagy and Hall 1974; Upreti et al. 2000; Zieslin and Gottesman 2008) and changes in other plant hormones such as indoleacetic acid (IAA) and abscisic acid (ABA) (Itai and Vaadia 1973; Quarrie 1980; Upreti et al. 1998; Bhatt et al. 2009). The study indicates that the decrease in IAA level in association with increase in the ethylene level in the flowers might be the important factors causing flower abscission under water stress (Bhatt et al. 2009).

Apart from inhibiting the photosynthetic rate through reducing stomatal conductance (Chaves 1991; Yordanov et al. 2000), drought stress also induces metabolic impairment (Bota et al. 2004; Dias and Bruggemann 2007, 2010). The water-limited conditions affect many physiological functions. The osmotic adjustment, deeper root growth and changes in hormonal balance were found to be the most effective mechanisms executed for water-stress tolerance. It has been observed that root dehydration (Davies and Zhang 1991) lead to stomatal closure and decrease in photosynthesis, with no change in leaf turgor. Stomatal closure was found to be more closely related to events in the root than in the shoot, and therefore, root physiological status plays an important role in modulating shoot behaviour (Masle and Passioura 1987; Milligan and Dale 1988).

Drought influences both stomatal and non-stomatal regulation of photosynthesis. The photosynthesis and photosynthetic capacity are reduced during limited water conditions. Further, the biochemical capacity was also affected by the water stress as indicated by a decrease in sucrose phosphate synthase (SPS) and invertase activities which affect the availability and utilization of sucrose. The SPS is considered to play a major role in the resynthesis of sucrose (Whittingham et al. 1979; Wardlaw and Willenbrink 1994) and sustain the assimilatory carbon flux from source to developing sink (Isopp et al. 2000). The decreased invertase activity might affect the ability to utilize sucrose (Liu et al. 2004) and also result in reduced ovary growth and reduced concentration of hexoses (Anderson et al. 2002). At cellular level, drought stress induces the production of free radicals which in turn may cause lipid peroxidation and membrane deterioration in plants. The production of these free radicals may also result in imbalance between antioxidant defences and the amount of reactive oxygen species (ROS) leading to oxidative stress (Van Breusegem et al. 2001). Though different views were proposed for the flower and flower bud abortion under water stress, the physiological mechanism controlling reproductive abortion, however, remains unclear.

Though genetic improvement can contribute to develop drought resistant varieties, the progress can also be achieved through developing and improving the plant adaptation strategies. Stepwise approaches to genetic improvement have been followed in enhancing the adaptability of vegetable crops to the tropical conditions; however, less importance was given to the root system dynamics and its growth under drought conditions. Maintenance of proper root growth is one of the important physiological traits for the tolerance of crop plants to drought. The modification of root system through grafting with physiologically compatible scion may also help in improving the plant tolerance to drought. Grafting in vegetable crops was found to be effective for reducing the effect of water stress and considerably improve water use efficiency under drought conditions (Bhatt et al. 2002) as observed in many other tree crops (García-Sánchez et al. 2007; Satisha et al. 2007). It has been found that the tolerant rootstocks strongly influence scion response to low soil moisture in terms of photosynthesis, stomatal conductance and carboxylation efficiency of crop plants (Iacono et al. 1998; Bhatt et al. 2002). This influence may be of great relevance in increasing the physiological potentiality of the plant under the low moisture stress and making it tolerant to drought. In beans (*Phaseolus vulgaris* L.), the osmotic potential of dehydrated scions of grafted plants was determined by the rootstocks, while in non-stressed scions, it was governed by the shoot (Sanders and Markhart 1992). Since eggplants were found to be more effective to water uptake than tomato root systems, it would be interesting to study their grafting potential under water-stress conditions. However, in certain studies, results did not confirm the advantage of eggplants when used as a rootstock for tomato (Abadelhafeez et al. 1975). In a study, Bhatt et al. (2002) found that the grafts of tomato responded differentially to different water-stress levels. Though no significant difference in photosynthesis was found between control and 50% stressed plants, a considerable reduction in photosynthesis was observed under 100% stress (Table 15.1). The mini-watermelons which were grafted onto a commercial rootstock have shown above 60% increase in the marketable yield under deficit irrigation conditions when compared to ungrafted melons (Rouphael et al. 2008a).

The higher yield in grafted plants was mainly attributed to an improvement in carbon dioxide (CO_2) assimilation and stomatal conductance (Bhatt et al. 2002). Grafting studies with ABA-deficient mutants of tomato showed that there is a chemical signal produced by the roots that controls stomatal conductance (Holbrook et al. 2002). It was also observed that in tomato, the grafts perform better after the release of water stress (Table 15.1). Grafts on brinjal rootstocks responded better under stress condition (Fig. 15.2 and Table 15.2).

15.3.2.2 High Moisture Conditions

Flooding and water logging are another important abiotic stresses and cause serious problems for the growth and yield of vegetable crops which are generally considered flood-susceptible crops. The occurrence of flooding conditions normally cause oxygen (O_2) deficiency which arises from a slow diffusion of gases in water and O_2 consumption by microorganisms and plant roots. Flooding affects the physiology of the vegetable plants. One of the earliest plant physiological responses to soil flooding is the reduction in stomatal conductance (Folzer et al. 2006). It causes an increase in leaf water potential (Smith and Ager 1988; Liao and Lin 1994), decrease in stomatal conductance resulting in significant reduction in carbon exchange rate (Bradford 1983) and elevation of internal CO_2 (Ci) concentration (Liao and Lin 1994). Water logging results in internal water deficit since it limits the water uptake (Parent et al. 2008). Further, the availability of sugars in plants is also affected because such conditions (flooding) tends to reduce the translocation of assimilates from leaves to root (Yordanova et al. 2004).

Some workers have found that flooding can cause a 10% reduction in yield (Bange et al. 2004) and 40% in severe cases (Hodgson and Chan 1982). The vegetative and reproductive growth of plants is negatively affected by flooding due to detrimental impacts on physiological functioning (Kozlowski 1984a; Gibbs and Greenway 2003). In sensitive crop plants, flooding causes leaf chlorosis (Drew and Sisworo 1977; Wang et al. 1996) and reduces shoot and root growth, dry matter accumulation and total plant yield (Kozlowski 1984b; Drew 1992; Huang et al. 1994a, b; Malik et al. 2002). Survival of tomato plants during flooding conditions is associated with the formation of adventitious roots (Kramer 1951). The resumption of shoot growth is attributed to a renewed supply of hormones from the new adventitious roots. Flooding stress causes epinasty, leaf chlorosis, necrosis and reduced fruit yield (Kuo and Chen 1980; Kuo et al. 1982).

In order to increase crop productivity in flooded soils, development of flood-tolerant varieties/lines is needed (Ezin et al. 2010). Flooding results in the inhibition of vegetative

Table 15.1 Photosynthesis (Pn) (μmol m^{-1} s^{-1}) and stomatal conductance (gs) (mol m^{-2} s^{-1}) as affected by moisture stress in grafted and ungrafted plants of tomato

Days after stress	Grafted						Ungrafted					
	Pn			gs			Pn			gs		
	100% stress	50% stress	Control	100% stress	50% stress	Control	100% stress	50% stress	Control	100% stress	50% stress	Control
3	6.2	10.0	10.9	0.12	0.18	0.18	5.0	9.0	9.5	0.12	0.18	0.15
5	5.8	10.0	11.0	0.12	0.19	0.19	3.0	10.3	10.5	0.05	0.16	0.19
7	3.4	10.8	11.1	0.09	0.19	0.19	1.3	10.2	10.5	0.04	0.16	0.17
Rec*	10.4	11.0	11.4	0.18	0.20	0.20	9.3	10.4	10.8	0.15	0.15	0.16
Final**	10.5	10.5	10.9	0.17	0.19	0.19	10.3	10.0	10.6	0.14	0.15	0.17

* recovery

** final observation

Source: Bhatt et al. 2002

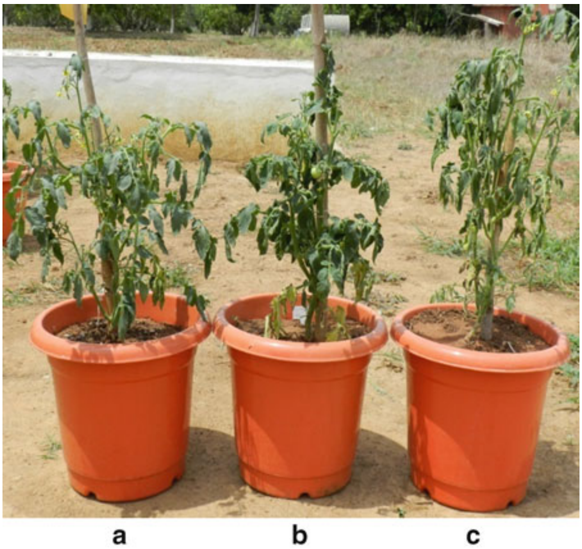

Fig. 15.2 Grafted tomato (cv. Arka Saurabh) plants after one week of drought stress. Plants were grafted on brinjal rootstocks BPLH (**a**) & Arka Neelkanth (**b**) and on own tomato rootstock (**c**)

Table 15.2 Leaf area (cm^2 plant^{-1}), total dry matter (g plant^{-1}) and fruit dry matter (g plant^{-1}) in grafted and ungrafted plants of tomato (cv. TO-5975) as affected by different levels of water stress

		Grafted			Ungrafted		
Parameter		100% stress	50% stress	Control	100% stress	50% stress	Control
Leaf area	(BRS)	2295.8	2340.0	2350.0	1303.5	1858.1	1884.5
	(FR)	3040.4	3387.2	3640.0	2870.6	3112.1	3519.9
Fruit dry wt.	(BRS)	1.36	2.23	3.08	3.24	4.10	4.84
	(FR)	10.70	13.34	16.90	5.23	5.44	7.23
Total dry matter	(BRS)	19.44	20.30	27.08	21.30	24.07	24.35
	(FR)	49.50	55.22	59.93	37.16	43.65	49.11

BRS before releasing stress, *FR* final reading
Source: Bhatt et al. 2002

and reproductive growth, changes in plant anatomy, development of adventitious roots (Hook and Scholtens. 1978) and the early leaf senescence and mortality (Erikson 1989; Wigley and Filer 1989; Shul'ga and Maksimov 1991). It has been found that in many tolerant plant species though the growth under anoxic conditions may be reduced by flooding, tolerant plants can resume normal growth rapidly once aeration of the roots has been restored, while such recovery was not found in sensitive species (Crawford 1982).

Generally, damage to crops by flooding is due to the reduction of O_2 in the root zone which inhibits aerobic processes. Low O_2 levels stimulate an increased production of an ethylene precursor, 1-aminocyclopropane-1-carboxylic acid (ACC), in the roots. It is found in tomato that although ACC is transported from the roots to the shoots, it has no direct effect on stomatal conductance (Bradford and Hsiao 1982). Leaf epinasty is a characteristic response of tomatoes to waterlogged conditions, and it is attributed to the accumulation of ethylene during such condition. Ethylene induces petiole epinasty with partial stomatal closure in waterlogged plants. The leaf epinasty may influence plant water balance by reducing light interception, which is considered a beneficial effect of epinasty. Many flood-resistant plants are able to develop avoidance mechanism to survive long-term floods by formation of aerenchyma (aerated tissue) either by cell collapse (lysigeny) or by the enlargement of inters cellular space resulting from cell separation without collapse (schizogeny). Another adaptation is to develop the

Fig. 15.3 Response of grafted and ungrafted plants of tomato to 5 days flooding at flowering stage

Table 15.3 Relative water content (RWC, %), osmotic potential (–Mpa), electrolyte leakage (%) and total chlorophyll content (mg chl/g FW) of grafted tomato plants on different brinjal rootstocks and self-rootstock at 7 days flooding

Grafts	Treatments	RWC	Osmotic potential	Total Chl. content
Arka Meghali/Arka Keshav	Control	94.2	0.70	1.30
	Flooding	81.2	2.82	0.89
A. Meghali/Arka Neelkanth	Control	88.0	0.73	1.24
	Flooding	75.0	2.35	0.89
A. Meghali/Mattugulla	Control	91.6	0.79	1.28
	Flooding	73.6	2.79	1.08
A. Meghali/BPLH-1	Control	93.8	0.74	1.44
	Flooding	73.8	2.79	0.69
A. Meghali/A. Meghali	Control	89.4	0.73	1.57
	Flooding	75.1	2.33	0.10

adventitious roots on the base of the shoot, the hypocotyl and upper part of tap root and stem nodes. The formation of adventitious roots takes place when the original root system becomes incapable of supplying the shoot with the required water and minerals (Mergemann and Sauter 2000). The ethylene and auxins play important roles in the formation of adventitious roots.

Most of the vegetable crops are highly sensitive to flooding. Problems caused by flooding may be solved by growing flood-tolerant varieties/lines but there is a lack of source of tolerance to flooding in crops like tomato. Therefore, the work is initiated in many laboratories world over to modify the root system by grafting the domesticated crop plants on wild or tolerant rootstocks. Grafting improved flooding tolerance of bitter melon when grafted onto *Luffa* (Liao and Lin 1996). In tomato, the grafted plants on brinjal rootstocks (Fig. 15.3) had lower osmotic potential, higher relative water content and greater chlorophyll contents during flooding condition (Table 15.3). In another study on watermelon, it was found that the decrease in chlorophyll content in grafted watermelon [*Citrullus lanatus* (Thunb.) Matsum and Nakai cv. 'Crimson Tide'] onto *Lagenaria siceraria* SKP (Landrace) was less pronounced compared to ungrafted water melons (Liao and Lin 1996; Yetisir et al. 2006).

Grafting of flood-intolerant bitter melon seedlings onto the flood-tolerant *Luffa* rootstock

Table 15.4 Photosynthetic rate (Pn, μmol m^{-2} s^{-1}), stomatal conductance (gs, mol m^{-2} s^{-1}) and internal CO_2 (Ci, ppm) response of different tomato grafts 3 days after releasing flooding

Grafts	Pn (μmol m^{-2} s^{-1})	gs (mol m^{-2} s^{-1})	Ci (ppm)
A. Meghali/A. Keshav	4.43	0.030	205
A. Meghali/A. Neelkanth	10.73	0.083	216
A. Meghali/Mattugulla	8.52	0.080	229
A. Meghali/BPLH-1	6.31	0.075	258

improved flood tolerance (Liao and Lin 1995). The formation of aerenchyma was also observed in grafted plants of watermelon when compared to ungrafted watermelon (Yetisir et al. 2006). It was also observed that the recovery after releasing the flooding was better in the plants of tomato grafted on brinjal rootstocks (Table 15.4). The study in various vegetable crops indicated that grafting improves the physiological response of the plants and also perform better after releasing the flooding. The formation of adventitious roots and aerenchyma tissue in grafted plants of watermelon was observed under flooding. The grafting of tomatoes on eggplant was recommended under flooding (AVRDC 2003, 2009).

15.4 Conclusion

Maintaining crop yields under adverse environmental conditions such as high and low temperature, drought and flooding conditions is probably the major challenge in horticultural crops. Climate change further enhanced the occurrence of these adverse conditions by erratic rainfall and thermal spells. Further, there is a lack of source of tolerance to drought, flooding and high- and low-temperature conditions in vegetable crops such as tomato, capsicum and chilli. Though stepwise approaches to genetic improvement have been followed in improving the adaptability of vegetable crops to the tropical conditions, less importance was given to the root system dynamics and its growth under drought conditions. Maintenance of proper root growth is one of the important physiological traits for the tolerance of crop plants to abiotic stresses. Grafting may be one of the promising tools for modifying the root system of the plant for enhancing plant tolerance to various abiotic stresses. However, there is a need to identify the tolerant rootstock and testing their grafting compatibility under various stress conditions. For this reason, the breeding of appropriate rootstocks is still a matter of trial and error, and the use of specific physiological fruits to select plants in the breeding programmed will be useful for future rootstock breeding. Future research programmes should focus on identification of the key-physiologically root-related fruits that are highly correlated to the rootstock traits of interest. The biomarkers (physiological and biochemical markers) may be identified and used to develop an effective method for the selection of rootstocks which improve the adaptability of vegetable and fruit crops to environmental stresses.

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Plantation Crops Response to Climate Change: Coconut Perspective

16

Kukkehalli Balachandra Hebbar, Doddaballapura Balasimha, and George Vettimoottil Thomas

Abstract

Plantation crops, mainly coconut, rubber, tea, coffee, oil palm, areca nut, cashew, and cocoa, are grown in ecologically sensitive areas such as coastal belts, hilly areas, and areas with high rainfall and high humidity. Among these coconut is a major multi-utility crop that plays a significant role in the economy of the countries, including 10 million farming communities in India. Climate change will affect coconut plantation through higher temperatures, elevated CO_2 concentration, precipitation changes, and increased weeds, incidence of pests and disease, and increased vulnerability of organic carbon pools. Unlike in seasonal crops, the impact of climate change will have long-standing ill effects in coconut since it is a perennial crop. In general, various approaches are used to mitigate risks associated with seasonal climate variability, including the adoption of the tolerant crop varieties and best management practices. In this chapter the response and adaptive strategies of coconut are discussed with respect to climate change and its associated consequences.

16.1 Introduction

Agricultural production in most parts of the world will face less predictable weather conditions than mankind experienced during the last century. Weather extremes will become predominant. Coastal and hilly areas are believed to be more vulnerable to climate change compared to other terrestrial areas. In these tracts in addition to the projected high temperature and drought, there is a serious threat of flooding and sea-level rise which may affect the livelihood of millions of people. Plantation crops are the predominant cropping systems in coastal and hilly tracts. Unlike in seasonal crops, the impact of weather aberrations will be having long-standing ill effects as the crops are perennial in nature; as a result, the region's economy will be adversely affected.

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Among plantation crops, coconut is the major crop in India grown in almost 2 m ha. It exerts a profound influence on the rural economy of the many states where it is grown extensively, and it provides sustenance to more than 10 million people. The export earnings derived by India from coconut are around Rs. 13,370 million. The processing and related activities centered on the crop generate employment opportunities for over two million people in India. It is projected that by 2025 the coconut demand is increased to 22 billion from the present supply of 15 billion nuts (Anonymous 2011). To meet the demand, adaptation measures that stabilize the yield under anticipated drought, flood and high temperature conditions of climate change need to be evolved. Coconut is grown between 20°N and 20°S latitude. It can be grown even at 26°N latitude, but the temperature is the main limitation. The optimum weather conditions for good growth and nut yield in coconut are well-distributed annual rainfall between 130 and 230 cm, a mean annual temperature of 27°C, and abundant sunlight ranging from 250 to 350 Wm^{-2} with at least 120 h per month of sunshine period. Since it is humid tropical crop, it grows well above 60% humidity (Child 1974; Murray 1977). The generally recommended level of major nutrients like NPK is at 500 g N: 320 g P_2O_5: 1,200 g K_2O per palm/year. The recommended irrigation levels are 200 l/palm once in 4 days or at 66% evaporation through drip irrigation (Rajagopal and Kasturi Bai 1999). Any deviations from these optimal conditions cause the palms to experience the stress conditions.

Climate change will affect coconut plantation through higher temperatures, elevated CO_2 concentration, precipitation changes, increased incidence of pests and diseases, and increased vulnerability of organic carbon pools. In order to predict the future coconut production, a Info crop-coconut simulation model was developed (Naresh Kumar et al. 2008). Simulation analysis using the model indicates that under all storylines, coconut productivity is projected to go up by 10% during 2020, 16% in 2050, and 36% in 2080 over current yields only due to climate change. However, in east coast yield is projected to decline by about 2% in 2020, 8% in 2050, and 31% in 2080 scenario over current yields due to climate change. Yield is projected to go up in Kerala, Tamil Nadu, Karnataka, and Maharashtra, while in Andhra Pradesh, Orissa, and Gujarat, it is projected to decline. Coconut has various adaptive strategies to withstand or overcome the stress conditions at morphological, physiological, biochemical, anatomical, and molecular levels (Kasturi bai et al. 2009). In this chapter the response and adaptive strategies of coconut are discussed with respect to climatic factors like high CO_2 effect and the consequences of climate change like drought and high temperature.

16.2 Drought

Drought stress affects coconut production in almost all coconut-growing countries since it is mainly a rainfed plantation (Coomans 1975; Mathes 1988; Bhaskara Rao et al. 1991). Hence, the productivity is low in these areas by approximately 50% of irrigated gardens. Coconut faces summer dry spells each year apart from the frequent occurrence of drought years. This is projected to increase further as the long-term climate data for 140 years in the humid tropics of India indicate cyclic pattern in rainfall with a declining trend in annual and southwest monsoon rainfall during the past 60 years (Krishna Kumar et al. 2008). Being perennial in nature, coconut palm had a long duration from the initiation of inflorescence primordial to nut maturity (~44 months) with longer pre-fertilization period (~32 months) than post-fertilization (12 months) period. Hence, the impact of drought occurring at any of the critical stages of the development of inflorescence affects nut yield (Kasturi Bai and Rajgopal 1999; Rajagopal et al. 1996, 2000) not only in current year but also in next 3 years to follow, thus making the problem more severe (Naresh Kumar et al. 2002).

The effects of water deficit on the physiology, growth, and productivity of coconut have been widely documented (Repellin et al. 1994, 1997;

Rajagopal and Kasturi Bai 1999; Prado et al. 2001; Azevedo et al. 2006; Gomes et al. 2007).

16.2.1 Anatomical and Morphological Traits

In coconut palm, only a single-stem growth unit is present since palms rarely show branching. The growth of shoot results from a terminal bud during a continuous growth cycle (Hallé et al. 1978). The axial vascular bundles of xylem and phloem in the stem are organized in close juxtaposition with extensive interconnection by vascular bridges minimizing isolated functional sectors of mass flux from roots to canopy. Hence, in coconut the stem highly integrates the whole organism, being central for coordinating processes that resemble the closed (unitary) growth of most animals rather than the open (modular) growth of most plants (Tomlinson 2006). Thus, the coconut stem acts as a water conductor and capacitor which enables it to withstand water stress as demonstrated in a study by Villalobos et al. (1992).

The fibrous root system (homorhizic) of an adult coconut can protrude as far as 3.0 m from the trunk, but most roots reach 1.5 m in length (Avilán and Rivas 1984; Cintra et al. 1992, 1993). Compacted layers of soil limit the distribution of the coconut root system. The root growth of coconut genotypes may shift to deeper sites in response to dehydration of superficial soil layers. Tall genotypes showed greater ability to produce deeper roots under water stress (Cintra et al. 1993) and found to have better ability to extract soil moisture from the entire soil profile.

Several water stress adaptive features were found in coconut leaflets. Waxy cuticle on the upper epidermis about two-fold thicker than on the lower epidermis, thicker cuticle at the edge, water tissue with thin-walled cells at the upper and lower angles of the straightened leaflet margin, xylem tracheids with thick lignifications, fibrous sheet encircling seven to eight large vascular bundles in a strong midrib, and tracheids with scalariform thickening in diminutive vascular bundles (Naresh Kumar et al. 2000). Drought-tolerant cultivars had more scalariform thickening on tracheids and large sub-stomatal cavities. Despite the latter trait, the cumulative effect of leaflet anatomical adaptations for drought tolerance decreases the contact between the cell and the leaflet internal atmosphere, reducing transpiration rate (E), stomatal conductance (g_s), and P_N but increasing WUE.

16.2.2 Leaf Photosynthesis

Under non-limiting conditions, coconut develops a large and highly productive canopy, being capable of an estimated 51 t ha^{-1} year^{-1} of total dry matter production (Foale 1993). Short-term responses of coconut to water stress such as low g_S and water potential which often impair P_N and E have been extensively documented (Repellin et al. 1994, 1997; Rajagopal and Kasturi Bai 2002). Carbon assimilation rate is impaired in both tall (Repellin et al. 1997; Prado et al. 2001) and dwarf genotypes (Gomes et al. 2007) in response to atmospheric and soil water deficit. Reductions of P_N from 7% to 47% and from 12% to 67% have been reported for dwarf and tall genotypes, respectively. Drought-induced photosynthetic reductions are initially attributable to limited CO_2 diffusion from the atmosphere to the intercellular spaces as a result of stomatal closure (Repellin et al. 1994, 1997). Non-stomatal factors have been demonstrated to contribute to the reduction in P_N both during a period of severe water deficit and during the recovery phase after resuming irrigation (Gomes and Prado 2007; Gomes et al. 2007). In addition, fluorescence measurements recorded by Kasturi Bai et al. (2006) indicated reduction in Fv/Fm (photochemical efficiency) with decreasing water potential, suggesting damage to photosynthetic apparatus under stress.

16.2.3 Response to Soil Moisture

Coconut has been considered as extravagant in water consumption. Jayasekara and Jayasekara (1993) estimated a daily transpiration between

30 and 120 l by an adult coconut tree with 35 leaves in the crown (150 m^2 of leaf area), depending on soil water content and evaporative demand of the atmosphere. Yusuf and Varadan (1993) estimated the water consumption by tall coconut tree in India as 115 l day^{-1} in summer and 55 l day^{-1} in winter. Studies with dwarf varieties have suggested a daily water consumption of 8–12 l $palm^{-1}$ in the first 6 months after planting in the field, 12–28 l $palm^{-1}$ from 7 to 12 months and 30–55 l $palm^{-1}$ from 13 to 18 months (Miranda et al. 1998). Mean E varied from 0.09 to 1.52 l day^{-1} m^{-2} leaf area in 3.5-year-old dwarf coconut palms, as estimated by measurements of xylem sap flux density (Araujo 2003). Taking the mean value of Araujo (2003) (0.8 l m^{-2} day^{-1}) and a leaf area of 140 m^2 in dwarf varieties (Ramadasan and Kasturi Bai 1999), the calculated transpirational water loss (114 l day^{-1}) agrees with the values reported by Jayasekara and Jayasekara (1993) and is only slightly higher than that reported by Yusuf and Varadan (1993) for tall varieties.

Compared to the tall varieties, some evidence suggests that dwarf varieties use water more extravagantly due to its elevated transpiration rate (IRHO-CIRAD 1992), greater number of stomata per unit leaf area (stomatal frequency), and lower wax content on the leaf surface (Rajagopal et al. 1990), as well as a poorer stomatal control of water loss (Passos and Silva 1990). Tall varieties, in contrast, show a more conservative water use (Voleti et al. 1993). Kasturi Bai et al. (1997) observed that West African Tall (WAT) behaves relatively better than the hybrids under drought conditions, due to lower g_s (0.10 mol m^{-2} s^{-1}) and, as a consequence, improved tissue water conservation.

WUE has been shown to vary among varieties and also among ecotypes of the same variety (Prado et al. 2001; Gomes et al. 2002). Passos et al. (1999), comparing three dwarf genotypes, observed that Malayan Yellow Dwarf (MYD) showed better WUE than the other two genotypes (Malayan Red Dwarf (MRD) and Brazilian Green Dwarf (BGD)). The superiority could be due to the following: (1) higher stomatal sensitivity to changes in leaf water potential; (2) higher g_s during the rainy season, which resulted in higher P_N and better leaf-cooling and nutrient-uptake capacity due to transpiration; and (3) a more developed root system, which leads to higher water-uptake efficiency. In another study Rajagopal et al. (1989) recorded higher WUE in unirrigated palms than in irrigated palms. Wide variability is seen between the cultivars and hybrids with a range in WUE between 28.8 and 69.3 gDM mm^{-1} water.

A positive relationship between vesicular-arbuscular mycorrhizae (VAM) colonization and water relation aspects, as measured by stomatal resistance and leaf water potential, was detected in five cultivars and hybrids of coconut (Thomas et al. 1993). Moreover, drought-tolerant genotypes had a greater proportion of roots with VAM colonization and a great number of roots with higher intensities of infection than the sensitive ones (Thomas et al. 1993).

16.2.4 Biochemical Responses and Osmotic Adjustment

Information concerning the protoplasmic tolerance to drought stress has led to the conclusion that coconut leaves have highly efficient systems that protect cell membranes and their intracellular components. Lipid composition, lipid peroxidation level, and the activities of enzymes related to oxidative stress are good indicators of dehydration tolerance in leaves of coconut. Water deficit induced a reduction in total leaf lipid content, mainly that of the chloroplast membranes, an effect particularly expressive in the less drought-tolerant genotypes (Repellin et al. 1994). In addition, an increase in the degree of lipid unsaturation in response to severe drought was also observed, which seems to be related to the maintenance of membrane fluidity, mainly in the chloroplasts (Repellin et al. 1997). Coconut cultivars considered drought tolerant showed a lower level of lipid peroxidation and higher activity of catalase, superoxide dismutase, and peroxidase than cultivars empirically classified as drought susceptible. Indeed, peroxidation level was negatively correlated (R^2>0.73) with activity of antioxidant enzymes (Shivashankar et al. 1991; Chempakam et al. 1993).

As for proline, though it is being reported as an important component of drought tolerance mechanisms in various genotypes (Kasturi Bai and Rajagopal 2000), Gomes and Prado (2007) demonstrated its poor effectiveness for turgor maintenance in two dwarf ecotypes, at least under severe water stress conditions.

16.3 Temperature

Under changing climate scenario, crops are predicted to be exposed not only to higher mean temperatures but also to more frequent short episodes of high temperatures (Solomon et al. 2007). Temperature can affect photosynthesis through modulation of the rates of activity of photosynthetic enzymes and the electron transport chain (Sage and Kubien 2007) and, in a more indirect manner, through leaf temperatures defining the magnitude of the leaf-to-air vapor pressure difference, a key factor influencing stomatal conductance.

High temperature (HT) stress during reproductive stages of crop development can significantly decrease components of plant yield (Prasad et al. 1999, 2000, 2006). Crops are sensitive to HT, particularly during flowering. Exposure to HT during flowering significantly decreases seed set in groundnut, rice, wheat, and sorghum (Prasad et al. 2000, 2002, 2006, 2008), resulting in lower seed yield. Seed set primarily depends upon function of pollen and ovule, successful pollination, fertilization, and post-fertilization (abortion) processes.

Many studies showed that pollen development during various phases of microsporogenesis was sensitive to HT stress (Salem et al. 2007; Prasad et al. 2008; Jain et al. 2010). Few reports documented the effects of HT on pollen morphological changes (Koti et al. 2005; Salem et al. 2007). In HT stress, the morphology of pollen was affected more severely, particularly in temperature-sensitive genotypes. The altered morphology includes a more flattened and collapsed pollen grain, which had lower pollen viability in HT stress conditions (Salem et al. 2007). HT stress during reproductive development has been reported to cause similar abnormal exine with deeply pitted and smooth regions (Salem et al. 2007). Because exine originates from the tapetum cells, the altered morphology observed may be due to alteration in the tapetal layer. Suzuki et al. (2001) reported that HT stress caused early degeneration of the tapetum layer and disrupted endoplasmic reticulum (*Phaseolus vulgaris* L.). Anatomical evidence explaining reasons for failure of pollen germination under HT stress is not clearly documented and needs attention. Similar anatomical studies of pollen in coconut and its use for screening the coconut cultivars for high temperature and water stress need high priority.

High temperatures can have both negative and positive impacts on growth and production in coconut. The negative impacts such as added heat stress, especially in areas at low to mid-latitudes already at risk today, but they also may lead to positive impacts in currently cold-limited high-latitude regions. Warming trends are noticed in most parts of the coconut-growing areas of Karnataka, Kerala, and Tamil Nadu. The ideal mean annual temperature for coconut growing is usually considered to be in the region of 29°C (27–32°C), with abundant sunshine and a well-distributed annual rainfall. High temperature increases both photorespiration and dark respiration, and thus, the total biomass production goes down. Regression analysis indicated an increase in leaf emergence rate with increased minimum temperature, increased inflorescence emergence rate with increase in maximum-temperature, pistillate flower production has curvilinear relationship with rainfall/month (150 mm/month-opt), and nut retention has curvilinear relationship with Tmax (32°C) and Tmin (20°C). Frequent but short periods of temperature below 15°C result in abnormalities of fruit such as bicarpellate nuts and lack of pollination under North Indian conditions. Preliminary investigations involving the Info crop-coconut model revealed that the coconut production in West Coast is less affected compared to East Coast with future climate scenarios (A2, B2, and A1B) (Kasturi Bai 2010).

16.4 CO_2 Concentrations

In almost all plants with C_3 photosynthetic pathway, such as coconut, the rate of photosynthesis is limited by the atmospheric CO_2 level. For these crops, higher CO_2 will allow greater photosynthetic production. Results of thousands of studies on the effects of increased CO_2 level on photosynthesis and crop growth are summarized in the Science website (www. CO_2science.org). For most of the crops, the benefit varied from 32% to 49% (Idso and Idso 2000). A further benefit may result from the fact that stomatal aperture, and hence transpiration, is reduced under high CO_2 (Ainsworth and Rogers 2007). This should lead to improved water use efficiency, i.e., the amount of biomass produced per unit water transpired will increase and could be important for future climate when water supply is projected to be scarce. However, Warren et al. (2011) found increased defoliation and mortality of some tree species at high temperatures and increased CO_2 may be because the reduced stomatal aperture meant that leaves were not cooled effectively. If this effect is widespread, some of the benefit of higher CO_2 might be offset by rising temperature.

In open-top chamber (OTC) experiments, it was observed that coconut seedling growth and biomass increased at elevated CO_2. At 550 and 700 ppm CO_2, the biomass increased by 8% and 25%, respectively, against ambient CO_2 concentration of 380 ppm (Hebbar et al. unpublished data). Elevated CO_2 to certain extent could offset the negative effect of temperature in coconut. The stimulatory effect of CO_2 under drought was less, and it could increase the biomass by only 8% at 700 ppm CO_2. Spindle leaf initiation and spindle leaf growth in coconut are very sensitive to climate change variables. Spindle leaf growth rate was approximately 2 cm/day with 550 and 700 ppm CO_2 as against 1.8 cm/day of ants grown in ambient condition. The higher growth rate of plants under elevated CO_2 was closely associated with the photosynthesis (PN). Photosynthesis was highest 14.4 µmol m^{-2} s^{-1} at 700 ppm CO_2 as against 10.14 under ambient condition. Application of 150% of recommended dose of fertilizer with 700 ppm CO_2 had an additive effect on PN, and it increased to 16.3 µmol m^{-2} s^{-1}. Chlorophyll fluorescence data measured in the same leaf where the PN was measured indicated that Fv/Fm (dark adapted values), which reflects the potential quantum efficiency of PSII, was on par in ambient and elevated CO_2 plants.

For a given amount of water, plants under elevated CO_2 produced higher biomass and thus had higher whole plant WUE (water use efficiency). WUE was 2.53 g/l under ambient condition, and it had increased to 3.14 at 700 ppm CO_2 which is in confirmation with the intrinsic WUE.

16.5 Interaction Effect of CO_2, High Temperature, and Drought

The interaction effect of elevated CO_2 and high temperature with drought and nutrients on growth and development of coconut seedlings was studied in an open-top chamber (OTC) at CPCRI, Kasaragod (Hebbar et al. unpublished data). High temperature (3°C above ambient) decreased the biomass by 10%. High temperature in addition to drought had a compounded effect and reduced the biomass by 16%. To certain extent, the elevated CO_2 could offset the negative effect of temperature in coconut. The stimulatory effect of CO_2 under drought and high temperature was less, and it could increase the biomass by only 8% with 700 ppm CO_2. Spindle leaf initiation and Spindle leaf growth was slow at high temperature. It was only 1.3 cm/day with high temperature and 1.7 cm/day with elevated CO_2 and high temperature as against 1.8 cm/day of plants grown in ambient condition. Similarly, spindle leaf growth rate significantly reduced in drought plants. Leaf splitting was faster when plants were grown under elevated CO_2 and was slow with drought and high temperature treatments. The stomatal conductance and the transpiration, on the other hand, were high in high temperature treatments 0.216 and 5.63 as against 0.125 mole m^{-2} s^{-1} and 2.58 mole m^{-2} s^{-1} with 700 ppm CO_2, respectively, indicating better intrinsic tolerance of plants to water limitation under elevated CO_2 concentration. The WUE was low at high temperature (2.28) and increased to 2.56 g l^{-1} in high temperature with elevated CO_2, indicating higher CO_2 could offset the effect of ET in coconut. Similarly, under drought too the WUE was the highest at 700 ppm CO_2 (2.70), and it was the least at high temperature (2.144).

Chlorophyll fluorescence data indicated that Fv/Fm (dark adapted values) which reflects the potential quantum efficiency of PSII was on par in ambient and elevated CO_2 plants, while it was less at high temperature treatments. It was the least with drought treatment. Yield indicates the proportion of light absorbed by chlorophyll associated with PSII was the least in high temperature treatment and it increased with increasing CO_2. However, even with high CO_2 the yield under drought was low because most of the energy seems to be wasted for non-photochemical quenching (qN).

16.6 Adaptation Strategies of Coconut to Climate Change

16.6.1 Higher Yield Realization with the Adoption of Scientific Technologies

Simulation analysis indicated that negative impacts of climate change can be overcome by adaptation strategies such as assured irrigation through drip system coupled with soil moisture conservation and by providing fertilizers/nutrients through organic and inorganic source in doses higher than those currently applied by the farmers. Such measures also maximize the positive impacts of climate change. Farmers who adopted soil moisture conservation practices or drip irrigation could reduce the drought impact on their plantations. In drought-affected coconut gardens, farmers could grow short-duration pulses, oil seeds, and millets for their sustenance.

In Kerala, providing more fertilizers along with summer time irrigation and following soil moisture conservation practices could further improve the positive gains due to climate change by 7–21% in different scenarios. In Karnataka, West Bengal, Gujarat, Maharashtra, and Orissa assured irrigation and providing more fertilizers could not only offset the negative impacts but could also result in higher yields.

In Northeastern States, providing summer irrigation and even low dose of fertilizers could further improve (in the range of 10–33%) the positive impacts of climate change. If coconut plantations in islands are managed scientifically by proper spacing, canopy management, summer irrigation, and even with low dose of fertilizers, the productivity could be enhanced to an extent of 2–25%.

Long-term coconut research carried out in the last few decades has perfected the approach for the identification of stress-tolerant cultivars and evolved various soil, water, and crop management techniques to manage the abiotic stress. The adoption of these techniques might help in stabilizing the yield in future climates.

16.6.2 Drought-Tolerant Cultivars Are Identified

The physiological and biochemical parameters for screening coconut to drought tolerance have been standardized. The physiological parameters and their critical levels are stomatal resistance (9 s cm^{-1}), transpiration rate (2.5 μg cm^{-2} s^{-1}), leaf water potential (−1.2 MPa), and relative water content. The biochemical parameters used are lipid peroxidation, superoxide dismutase, peroxidase, catalase, polyphenol oxidase, and acid phosphotase and nitrate reductase. Based on the above screening parameters, the drought-tolerant cultivars identified are West Coast Tall (WCT), Laccadive Ordinary (LO), Andaman Ordinary (AO), WCT × COD, and LO × GB (Kasturi Bai et al. 2009).

16.6.3 Cultural Practices, Soil Conservation, and Water Management Techniques Are Evolved to Manage the Drought

16.6.3.1 Soil Management

- Mulching of basin with coir dust, 50 kg/palm
- Burial of husks in 3 or 4 layers
- Application of green manures or organic manures (FYM), 50–100 kg/palm
- Spreading dried coconut leaves and other organic residues (mulching effect)
- Addition of tank silt at 100–200 kg/palm (improves organic matter and water-holding capacity)
- Spreading of 2 kg NaCl around the palm basin
- Organic agriculture to increase soil's water-retention capacity

16.6.3.2 Soil Conservation

- Terracing the palm basins in sloppy lands to interrupt runoff of water and to enhance soil moisture.
- In situ (land configuration, mulching, etc.) and ex situ (ponds, micro water harvesting structure, jalkund, etc.) rain water harvesting.
- Bunding the field to prevent runoff of water. These measures would help in rainfed orchards.

16.6.3.3 Water Management

- Pitcher irrigation: Bury two or three earthen pots/hollow bamboos and fill them with water to moisten subsoil.
- Drip irrigation: two or three drippers on palm to wet subsoil layer.
- If adequate water is available, irrigate with 200 l water/palm once in four days. Mulch with dry leaves.
- Avoid flooding the basins. If water resources are good, save for future irrigation.
- Effective recycling of wastewater from backyards.

16.7 Coconut Is an Excellent Tree Crop for Climate Change Mitigation

16.7.1 Carbon Sequestration and Carbon Stocks in Coconut

Plantation crops have significant potential for offsetting and reducing the projected increases in greenhouse gas (GHG) emissions and are regarded as an important option for greenhouse gases mitigation. Aboveground biomass in coconut varied from 15 to 35 CERs depending on cultivar, agroclimatic zone, soil type, and management (Naresh Kumar 2009). Annually sequestered carbon stocked in the stem in the range of 0.3–2.3 CERs. Standing C stocks in 16-year-old coconut cultivars in different agroclimatic zones varied from 15 to 60 CERs. Annual C sequestration by coconut plantation is higher in red sandy loam soils and lowest in littoral sandy soils. Simulation results indicated that the carbon sequestered and stored in stem in coconut plantation in four states, Kerala, Karnataka, Tamil Nadu, and Andhra Pradesh, is to the tune of 0.732 million tons of carbon every year. These values can dramatically go up if all other aspects of carbon sequestration are taken into consideration.

16.7.2 Coconut Can Check Erosion and Wind Speed

Probably, coconut is the only crop next to mangroves that grows well in coastal areas. It is the best-suited crop for climate change situations as it can withstand temporary waterlogging conditions like floods and tides with special adaptability against strong winds, storms, and cyclones. It has a fibrous root system spread over few meters which not only takes up water and nutrients and anchors the plant but also helps in checking the erosion in high rainfall areas. Coconut orchards also act as strong windbreaks and reduce storms and cyclones.

16.8 Perspective for New Investigation

Adapting to future climate change might require farmers to use management practices and technologies that are beyond those existing today. Research must play proactive role to generate necessary responses and technologies that farmers will need to handle such future challenges. Over the last few decades, scientific effort has opened up different approaches to tackle the problem: Plant physiology has provided new tools to understand the complex network of drought-related traits, and several drought-related traits useful for improving selection efficiency have been identified. Molecular genetics has led to the discovery of a large number of loci affecting yield under drought or the expression of drought tolerance-related traits and has provided genes that are useful as candidate sequences to dissect quantitative trait loci. A Info crop-coconut simulation model has been developed and validated to make the impact assessment of coconut production in future climates of different agroclimatic zones using crop, weather, and soil inputs. The challenge for future investigations is the integration of simulation models with physiology and molecular genetics, leading to the identification of the most relevant adaptive technologies to combat the climate change effect.

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Impact of Climate Change on Cashew and Adaptation Strategies

17

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Abstract

Cashew (*Anacardium occidentale* L.) is an important export-oriented horticultural crop of our country. Cashew is presently grown in an area of 0.945 million ha with annual production of 0.653 million t of raw cashew nuts in the country (DCCD Cashew Cocoa J 1:23, 2011). Climate change may pose problem for cashew cultivation since cashew is grown in ecologically sensitive areas such as coastal belts, hilly areas and areas with high rainfall and humidity. The flowering, fruiting, insect pest incidence, yield and quality of cashew nut and kernels are more vulnerable for climate change. Unseasonal rains and heavy dew during flowering and fruiting periods are the major factors which adversely affect the yield and quality of cashew nut. Cloudy conditions, high RH and heavy dew are favourable for outbreak of insect pests and diseases. Drought conditions drastically reduce cashew nut production. The climate change-induced drought can be partially mitigated by adopting mulching, conservation agriculture and soil and water conservation measures, by providing protective/drip irrigation/fertigation during the fruit development stages. The sea level rise due to the melting of glaciers as a result of increase in temperature may also pose problem for cashew cultivation since large proportion of cashew plantations exist in Eastern and Western Coastal regions of India. Cashew is ideal crop for carbon sequestration. Based on research undertaken at Directorate of Cashew Research (DCR), it was found that cashew genotype (VTH-174) trees of 7 years old sequestered about 2.2-fold higher carbon (C) under high-density planting system (625 trees/ha) as compared to normal-density planting system (156 trees/ha). Carbon storage by cashew has been estimated as 32.25 and 59.22 t CO_2/ha at 5th and 7th year of growth, respectively, under high-density planting.

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17.1 Introduction

Cashew (*Anacardium occidentale* L.) is an important export-oriented horticultural crop of our country. Cashew is presently grown in an area of 0.945 million ha with annual production of 0.653 million t of raw cashew nuts in the country (DCCD 2011). The highest production of about 0.700 million t was realized in 2008–2009 from an area of 0.893 million ha. Most of the area under cashew is in East-Coast and West-Coast regions of the country. In India, cashew is grown mainly in Maharashtra, Goa, Karnataka and Kerala along the West Coast and Tamil Nadu, Andhra Pradesh, Odisha and West Bengal along the East Coast. It is also grown to a limited extent in nontraditional areas such as Bastar region of Chhattisgarh and Kolar (Plains) region of Karnataka, Gujarat and Jharkhand and in North Eastern Hill region. The current productivity of cashew in the country is of 0.72 t/ha. Low productivity of cashew in India is a matter of concern.

Cashew is mostly grown as a rainfed crop, and the yield and quality of nut is largely dependent on climatic and weather conditions. Any change in climate has direct impact on reproductive phase of cashew. With climate change, there will be various impacts on cashew production such as reduction in yields, variation in flowering, fruit setting, nut development and kernel quality, higher incidence of pests and diseases and water stress. It has been reported that the maximum temperature, humidity and rainfall are the major climatic factors which determine the productivity of cashew. The RH during pre-flowering stage is the key factor in explaining the yield variation in cashew plantations (Haldankar et al. 2003). Prolonged rainfall during flushing and flowering drastically affect the yield and quality of nuts. Unseasonal rains during the nut development stage may lead to immature fruit drop and poor nut quality. It was shown that nut size and kernel weight of cashew were much influenced by maximum temperature during the nut development stage (Prasada Rao et al. 2010). Despite the economic importance of cashew, few studies have sought to understand the influence of climate variability on cashew. The challenge for cashew crop will be to improve yields in marginal lands under rainfed conditions where the harsh environment strongly limits crop growth, productivity and quality of the produce.

17.2 Effects of Climate Change on Productivity and Quality of Cashew Nut

Cashew requires relatively dry atmosphere and mild winter (15–20°C minimum temperature) coupled with moderate dew during night for profuse flowering. Adaptability studies at Directorate of Cashew Research (DCR), Puttur using GIS indicated that cashew can grow at elevations ranging from 0 to 1000 m above mean sea level (MSL). However, the productivity is highest up to the altitude of 750 m above MSL. The average annual rainfall distribution in cashew areas ranged from low rainfall (300–600 mm in Gujarat) to high rainfall (2,700–3,000 mm in West-Coast and NEH region), but the productivity is highest in regions with a mean annual rainfall distribution of 600–1,500 mm. The mean annual temperature ranged from 20°C to even more than 27.5°C, and the productivity of cashew is higher in regions where the mean annual temperature ranged from 22.5°C to 27.5°C. The productivity of cashew is higher in regions where the minimum temperature ranges from 10°C to 22°C and is lower in regions where the minimum temperature drops below 10°C.

The rainfed cashew crop is highly sensitive to changes in climate and weather, particularly during reproductive phase. High temperature (>34.4°C) and low RH (<20%) during afternoon cause drying of flowers, resulting in yield reduction. Unseasonal rainfall and heavy dew during flowering and fruiting intensify the incidence of pests and diseases as well as deterioration of raw cashew nuts and finally affect the quality of kernels extracted from such blackened nuts. Unseasonal rainfall of about 201 mm received at DCR farm during 15–25 March 2008 had affected the

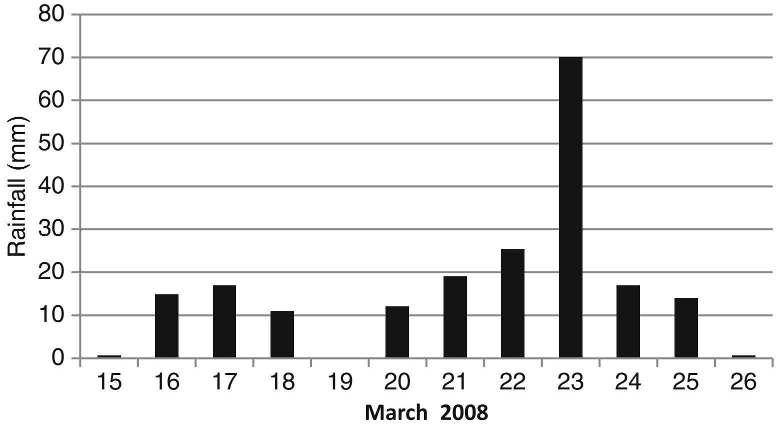

Fig. 17.1 Unprecedented rainfall received in March 2008

yield and quality of nut drastically (Fig. 17.1). The peak harvesting of nuts was over by 15 March 2008, and nuts were spoiled in field due to over-absorption of rainwater. Continuous rains did not permit drying of nuts immediately resulting in poor quality and caused the blackening of nuts, or nuts start germinating in the tree itself. Large quantity of nuts which could not be picked up in time germinated in the field. The collected nuts could not be dried in time due to non-availability of good sunshine hours because of continuous and unseasonal rains, resulting in poor quality of nuts. The excess moisture content in raw cashew nuts damages the kernel inside and changes its colour from white to cream. It has been estimated that the nut yield losses due to unseasonal rains ranged from 50% to 65% in March 2008.

Month-wise nut yield collected from cashew plantations at DCR for the past 5 years (2006–2010) (Table 17.1) showed that the nut collection normally starts from January and lasts up to May as in case of 2005–2006 and 2006–2007. Untimely/unseasonal rains during March 2008 caused considerable damage to the flowers, tender nuts and matured nuts in the trees and also matured nuts fallen on the ground and thereby resulted in poor quality of nuts. In contrast, during the previous 2 years (2005–2007), no rains were received during the corresponding period with good yield (Table 17.2). Performance of the crop is good if continuous rain is not received until May allowing

Table 17.1 Trends in raw cashew nut production for the last five years (2006–2010) at DCR farm

Year	Month	Production of raw cashew nuts (kg)
2006	January	1,700
	February	5,925
	March	8,252
	April	3,961
	May	1,162
	Total	21,000
2007	January	94
	February	2,792
	March	10,242
	April	9,547
	May	525
	Total	18,339
2008	January	488
	February	7,627
	March	10,049
	April	1,832
	May	1,000
	Total	20,995
2009	January	2,384
	February	3,977
	March	5,530
	April	2,967
	May	1,567
	Total	16,425
2010	February	4,167
	March	6,043
	April	8,281
	May	1,535
	Total	20,026

Table 17.2 Rainfall pattern (mm) from September to August from 2005–2006 to 2010–2011

Month	2005–2006	2006–2007	2007–2008	2008–2009	2009–2010	2010–2011
September	362	1,003	399	263	429.6	467.6
October	263	409	265	212	112.7	257.5
November	47	87	117	49	225.6	360.5
December	0	0	0	17	56.6	53.6
January	0	0	0	0	39.0	0.0
February	0	0	0	0	0.0	0.0
March	0	0	201	5.8	11.0	0.0
April	0	18	27.9	38.3	80.8	83.6
May	651	118	46.6	159.6	145.2	220.6
June	815	954	854.2	360.3	816.4	1,085.6
July	1,126	1,114	715	1,828	1,150	1,025
August	354	690	465	430	647	813.7

Table 17.3 Time of bud break of test varieties at RARS, Pilicode, from 1995–1996 to 1998–1999

	Time of bud break (25%) in test varieties				
Variety	1995–1996	1996–1997	1997–1998	1998–1999	Mean
Anakkayam-1	26 September	30 October	23 October	03 November	21 October
Madakkathara-1	22 September	02 November	05 October	03 November	16 October
Kanaka	08 October	14 November	30 October	15 November	01 November
Madakkathara-2	28 October	19 November	16 December	17 November	20 November
Mean	06 October	09 November	02 November	10 November	30 October

Source: Prasada Rao et al. (2001)

major harvesting to be over. A few summer rains are desirable for the crop but should not be in excess. Flowers exposed to heavy rains accompanied with high wind velocity resulted in flower drop and occurrence of fungal diseases during flowering phase. Pollinating insect activity also reduced to the minimum, resulting in poor setting of nuts. It has been estimated that the total nut yield losses were 50% with heavy loss (65%) during peak harvesting period with poor quality due to unseasonal rains received in March 2008.

Cashew genotypes vary distinctly in their heat unit (day °C) requirement. Anakkayam-1 (early variety) requires only 1953 heat units (day°C) for reproductive phase, while Madakkathara-2 (late variety) requires 2,483 heat units (day°C). Cashew kernel weight is reported to be positively correlated with heat units especially for mid and late varieties. Continuous rains without critical dry spells and late winter rains delay the bud break in cashew. A dry spell of 7 days is usually necessary 30 days prior to the bud break. Late and extended winter rains reduce the number of bright sunshine hours invariably which results in delaying of bud break and better availability of soil moisture during flowering (December and January). Incessant rains until November in 1998 delayed the bud break. The delay in bud break was prominent in early varieties. In late varieties, bud break was normal, because the required dry spell of 7 days was met 22–26 days before bud break (Table 17.3).

Peak flowering was early (8 December) during normal years (1995–1996) and late (29 December) in aberrant climate situations (1997–1998) which received late winter rains during November and December 1997 (Table 17.4). There was significant delay in peak flowering in Madakkathara-2 and Kanaka (13-1-98) during 1997–1998; however, early varieties flowered on normal dates. The delay in mean flowering date during 1997–1998 may be attributed to the late season types as they flowered very late.

Table 17.4 Time of flowering of test varieties at RARS, Pilicode, from 1995–1996 to 1998–1999

	Time of flowering (50%)				
Variety	1995–1996	1996–1997	1997–1998	1998–1999	Mean
Anakkayam-1	28-11-95	04-12-96	02-12-97	07-12-98	3 December
Madakkathara-1	25-11-95	06-12-96	05-12-97	07-12-98	5 December
Kanaka	17-12-95	15-12-96	13-01-98	26-12-98	29 December
Madakkathara-2	22-12-95	25-12-96	2-02-98	21-12-98	1 January
Mean	8 December	13 December	29 December	17 December	17 December

Source: Prasada Rao (2002)

17.3 Effects on Insect Pest Incidence

Cashew is reported to be infested by several insect pests, thereby limiting the production considerably. One of the main reasons for reduction of cashew nut yield is the occurrence of an important sucking insect pest, tea mosquito bug (TMB) (*Helopeltis antonii* Signoret), during the cropping season. The incidence of the pest has been recorded from various cashew-growing tracts of the country, and its incidence and severity are highly dependent on climate and weather factors. The pest causes damage on the tender parts of the cashew plant such as tender shoots and flushes, inflorescence and immature fruits. Both nymphs and adults suck sap from tender shoots and leaves, from floral branches and from developing nuts and apples by making a number of feeding lesions. During outbreak situation, the entire flush dries up and the trees present a scorched appearance. The pest population commences from October, and depending on the location and climatic conditions, it continues till the end of the cropping season. Although the pest population exists in cashew orchards at varying levels during the whole year, the increase of population synchronizes with the flushing and flowering period. It reaches a peak during the early to mid blossom period (December to February). The production loss from the TMB alone is estimated to be about 30%. This pest has got potential to cause 100% loss in yield in severe cases.

Several researchers have reported the seasonal incidence of the TMB and indicated that the pest population levels are low during the months of April to May and that the pest is very negligible during the rainy season (Rai 1984). Data on pest incidence of TMB at Kasaragod (Kerala) and Chintamani (Karnataka) indicated that pest population is relatively higher in the West Coast. However, the seasonal trend of pest population in West Coast and maidan tracts is similar and coincides with the flushing and flowering stages (December to February). Studies on pest occurrence in relation with the ambient weather parameters by Pillai et al. (1984) showed that the population of TMB is very low (1.6% damaged shoots) during October and reached a peak during January (40.6% damaged shoots) when the minimum temperature is very low (19.4°C). The peak period also coincided with the minimum relative humidity levels (51.6%). This indicates that any change in climate leading to lower relative humidity can favour the pest build-up. Pest population build-up was noticed during December to January when the mean duration of bright sunshine hours ranged between 9.2 and 9.8 h.

A multiple regression prediction model was developed based on weather data and pest population from 1988 to 1998 with 88% accuracy of prediction of pest incidence. The regression model, $Y = 0.648\ X_1 + 0.0022\ X_2 + 0.048\ X_3 - 0.073\ X_4 - 0.642\ X_5 - 0.597\ X_6 - 0.272\ X_7 + 30.473$ was developed based on the pooled data of the TMB population (Prasada Rao 2002), where, Y= predicted pest population, X_1 = sunshine hours (h/day), X_2= rainfall (mm), X_3 = morning relative humidity (%), X_4 = evening relative humidity (%), X_5= maximum temperature (°C), X_6 = minimum temperature (°C) and X_7 = number of rainy days.

The model helps in predicting subsequent TMB population one month in advance based on the prevalent weather parameters. An increase in

Table 17.5 Effect of minimum temperature on pest population of TMB

Night surface air temperature (°C)	Intensity of TMB
14 to 18	Moderate to severe
12 to 14	Low to moderate
10 to 12	Low
<10	Nil

Source: Prasada Rao (2002)

mean temperature to the tune of 1°C causes a reduction in the pest population up to 46% as indicated by the 'r' value of 0.642 for X_5 (maximum temperature °C).

Studies on the relationship between weather parameters and the population dynamics of TMB on cashew indicated that minimum temperature is negatively correlated with the pest incidence (Godse et al. 2005). The build-up of pest population commenced with the emergence of new flush during October after the cessation of monsoon shower, and the pest remained in the field until January. The major outbreak was reported in November, coinciding with the emergence of panicles, reaching the peak in December. The minimum temperature plays a major role in the incidence of pest population. The favourable minimum temperature for TMB incidence ranged between 13°C and 18°C. Low temperature (12°C) is antagonistic for pest build-up (Table 17.5).

Though cashew flowered profusely during 1995–1996 and 1998–1999, but there was a marked reduction in yield in 1998–1999 in Kannur and Kasaragod districts of Kerala. This could be ascribed to unprecedented incidence of pests aggravated by heavy dew in February 1998. Rain received during flowering and harvesting in 2008 increased the incidence of pests and diseases, resulting in very poor yield and quality (Prasada Rao 2002).

Apart from the damage caused by the infestation of TMB, infection of the panicles by the fungal pathogens, viz., *Colletotrichum gloeosporioides* and *Gloeosporium mangiferae*, has been reported to cause drying up of young shoots, inflorescence and immature nuts in cashew. The characteristic symptom is the drying of floral branches. The symptoms appear as minute water-soaked lesions on the main rachis and secondary rachis. The lesions develop into bigger patches and result in drying up of the inflorescences. The incidence is very severe when cloudy weather prevails. The incidence of this disease is being reported from different new locations in which it was not prevalent earlier. High RH in forenoon during December–February both in 1997 and 1998 and the minimum temperature of 18–20°C were found to be favourable for sporulation by fungi. A significant increase in dew was one of the most important factors which favoured the growth, sporulation and spread of fungi. Cloudiness leading to fewer bright sunshine hours (2 h/day) followed by dew triggered the growth, sporulation and spread of fungal pathogens causing inflorescence blight during 1998–1999 in Kannur and Kasaragod districts (Prasada Rao 2002).

Studies on seasonal incidence of cashew pest complex with weather parameters in Andhra Pradesh by Rama Krishna Rao and Haribabu (2003) reported that incidence of shoot and blossom webber was severe from July to October and February to March with a peak during first fortnight of September exhibiting a negative correlation with maximum temperature, while nonsignificant relationship with minimum temperature, relative humidity and rainfall. Leaf miner was severe from September to December with a peak during first fortnight of November. Relative humidity and rainfall had positive correlation with leaf miner incidence, while maximum and minimum temperature had no significance. Weevil population was severe from first fortnight of August to second fortnight of October with a peak during first fortnight of September having positive correlation only with rainfall.

17.4 Effects of Salinity on Cashew

The tsunami in coastal Tamil Nadu on 26 December 2004 severely affected cashew crop. Most of the standing crop was inundated with salty sea water ingressing in the mainland. Four cashew trees remained healthy and unaffected showing salt tolerance, and scions of these trees

Table 17.6 Effect of soil and water conservation techniques on run-off, soil loss and soil moisture content

Treatment	Run-off (% of annual rainfall)	Soil loss (t/ha/year)	Soil moisture (March 2004–2010) (% on dry basis)
Modified crescent bund	22.3	4.6	15.6
Coconut husk burial	20.4	4.8	15.8
Control	36.9	9.7	11.6

were brought and grafted. These grafts were planted in germplasm plot for further studies. Most of the cashew varieties are sensitive to salinity. Rise in sea water level due to climate change conditions may adversely affect the cashew plantation. Electrical conductivity of 1.48 dS m^{-1} in irrigation water is a threshold tolerance for precocious cashew during the initial growth (Carneiro et al. 2002).

17.5 Adaptation Strategies to Reduce the Vulnerability of Cashew to Climate Change

There are both threats and opportunities for cashew growers with climate change: the key is in understanding the likely impacts and then managing the risks. Developing adaptation strategies such as adoption of soil and water conservation measures, mulching, supplemental irrigation, drip irrigation, fertigation and carbon sequestration is essential to reduce the vulnerability of cashew to climate change.

17.5.1 Soil and Water Conservation Measures

In India, cashew is generally grown as a rainfed crop on neglected land unsuitable for any other crop. Cashew experiences severe moisture stress from January to May, adversely affecting its flowering and fruit set. In order to harvest the rainwater and to make it available to the cashew plant during critical period, an in situ soil and water conservation and rainwater harvesting are very important. Based on studies at DCR, soil and water conservation measures, such as modified crescent bund, at 2 m radius having a crescent-shaped bund of 6 m length, 1 m width and 0.5 m height on the upstream of the plant so that a trench of 6 m length and 50–75 cm deep will be formed while making the bund and coconut husk burial, trenches of size 5 m length, 1 m width and 0.5 m depth in the middle of four plants with coconut husk-buried treatments increased the growth of cashew plants and cumulative cashew yield with coconut husk burial: 6.60 t/ha and modified crescent bund: 6.45 t/ha compared to control (4.88 t/ha) and other treatments indicating 32–35% increase in yield. The net profit from cashew garden for the first 7 years (5 harvests) with proper soil and water conservation ranged from Rs. 2,02,445 to 2,02,304/ha, whereas in control it was Rs. 1,44,630/ha. Modified crescent bund and coconut husk burial treatments reduced the annual run-off by 22.3% and 20.4% of the annual rainfall, respectively, compared to 36.9% of the annual rainfall in control and soil loss (4.6 and 4.8 t/ha/year, respectively, as compared to 9.7 t/ha/year in control) and increased the mean soil moisture content (15.6% and 15.8% dry basis, respectively, compared to 11.6% dry basis in control in March) (Table 17.6). The harvested rainwater increased the ground water level in nearby wells and ponds. Hence, the barren land even in steep slopes can be effectively utilized for cashew cultivation with proper soil and water conservation measures like modified crescent bund or coconut husk burial in staggered trenches opened across the slope (Rejani and Yadukumar 2010).

Reduction in peak run-off and increase in recession time and ground water recharge due to soil and water conservation practices have been reported by several workers (Deshmukh et al. 1992). Badhe and Magar (2004) reported that trapezoidal-shaped staggered trenches (230/ha) having dimensions of 4.5 m length, 0.60 m top width, 0.30 m bottom width and 0.30 m depth were effective for reducing run-off and conservation of soil and nutrients. Mane et al. (2009) demonstrated that continuous contour trench (0.50 × 0.60 m) is the best soil conservation practice for cashew on areas having 7–8% slope.

17.5.2 Mulching

Cashew is often planted in areas which are totally dry and unsuitable for cultivating any other crop, and the availability of moisture is very low. Under such situations, mulching is useful to conserve soil moisture for a long period. The basin area of cashew plants can be mulched either with green leaves, dry leaves or weeds soon after planting. Black polythene mulch was helpful to conserve soil moisture (Nawale et al. 1985). Using coconut coir pith as soil mulch in cashew plantations resulted in 14.15% more water retention and suppression of weeds to an extent of 73.52% (Kumar et al. 1989). Formation of terrace and crescent bund and mulching the base area with cashew leaf litter and other jungle growth available in the orchard are helpful.

17.5.3 Green Manuring in Cashew

Soil moisture and fertility status of the soil in cashew orchard can be increased by growing green manuring crops like gliricidia, sesbania, sunhemp and cover crops between two rows of cashew. Based on studies at DCR, the dry matter production of green biomass was about 7.65, 5.75, 2.25 and 1.63 t/ha/year from gliricidia, sesbania, sunhemp and cover crop, respectively. The nutrient addition to soil was about 186 kg N, 23.6 kg P_2O_5 and 126.2 kg K_2O and 141 kg N, 17.9 kg P_2O_5 and 162.3 kg K_2O/ha through gliricidia and sesbania, respectively. Higher soil moisture content was observed in cashew orchard with green manure crops such as gliricidia (17.0–18.6% dry basis), sunhemp (17.8–18.3% dry basis) and sesbania (15.5–18.2% dry basis) compared to control (15.5–17.0% dry basis).

17.5.4 Irrigation

Cashew is generally grown as a rainfed crop, but the yield can be doubled if irrigated. The largest area under cashew cultivation is along the steep hillocks of West-Coast region of India where the mean annual rainfall ranges from 3,000 to 3,500 mm with 80% of its contribution during June to September. Due to the non-uniform distribution of rainfall, cashew experiences severe moisture stress from January to May which adversely affects its flowering and fruit set, resulting in immature nut drop and lower productivity of cashew orchards. During fruiting season of cashew (February to May), a mean rainfall of around 67–415 mm is received. The water deficit is highest during March to May (112–183 mm). Cashew yields can be enhanced by providing protective irrigation with 200 L of water per tree once in 15 days from January to March during the summer season. Irrigation can be started after the commencement of flowering for better nut set, filling and yield. It has been reported that fertigation saved 50% in the fertilizer requirement and doubled the cashew yield (Richards 1993; Yadukumar and Mandal 1994; Mishra et al. 2008).

17.5.5 Carbon Sequestration

Since carbon sequestration is an essential component of mitigation of greenhouse gases, it is important to assess the sequestration potential of crops. Sequestration of C from plant biomass into soil organic carbon (SOC) is a key strategy for controlling gaseous C emission from agriculture. It has been estimated that SOC sequestration potentially could offset about 15% of the global CO_2 emission. Cashew has dense green leaves with good photosynthetic capacity, and it can also be grown in high-density planting system. Cashew is suitable crop for carbon sequestration. It can be grown in vast degraded/wasteland existing in cashew-growing regions. Based on research undertaken at DCR, it was found that 7-year-old trees of cashew genotype VTH-174 sequestered about 2.2-fold higher carbon under high-density planting system (625 trees/ha) as compared to normal-density planting system (156 trees/ha). Carbon storage by cashew has been estimated as 32.25 and 59.22 t CO_2/ha at 5th and 7th years of growth, respectively, under high-density planting. The extent of carbon sequestered will depend on the amounts of C in standing biomass, age of the crop, tree density, variety, etc.

17.6 Conclusions

Cashew is mostly grown as a rainfed crop in India; therefore, its performance depends mainly on climate. The crop is sensitive to extreme climatic events of rainfall, drought and high wind velocity during reproductive phase. Suitability studies for cashew using GIS indicated that the productivity of cashew is higher in regions up to the altitude of 750 m above MSL, a mean annual rainfall distribution of 600–1,500 mm, and the minimum temperature ranges from 10°C to 22°C and is lower in regions where the minimum temperature drops below 10°C. Unseasonal rains and heavy dew during flowering and fruiting stages are the major factors which adversely affect the nut yield and quality of cashew. Late varieties with more heat unit requirement yield more than early varieties requiring lesser heat units. Cloudy conditions, high RH and heavy dew are favourable for outbreak of insect pests and diseases. The favourable minimum temperature for incidence of tea mosquito bug (TMB) ranged between 13°C and 18°C. Low temperature (12°C) is antagonistic for pest build-up. The production loss from the TMB alone is estimated to be about 30%. This pest has got potential to cause 100% loss in yield in severe cases. The adverse effects of climate change on cashew can partially be mitigated by adopting mulching and soil and water conservation measures, by providing protective/drip irrigation/fertigation during the fruit development stages. The perennial cashew crop has potential for carbon sequestration for mitigation of climate change.

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18

Adaptation and Mitigation Strategies for Climate-Resilient Oil Palm

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Abstract

The impacts of climate change on oil palm are being witnessed in Malaysia, Indonesia, Columbia, and other oil palm-growing nations of the world. Climate change might worsen existing regional disparities as it will reduce oil palm yields mostly in lands located at lower latitudes, where many developing countries are situated. Being grown as an irrigated crop in India, oil palm is likely to be more vulnerable due to excessive use of natural resources particularly water with poor adaptive mechanisms. The water requirement is estimated to increase by 10% for every 1°C rise in temperature. Under such situations, when oil palm yield decreases, small and marginal oil palm growers would be affected most. Hence, consequences of climate change could be severe on livelihood security of the poor in the absence of better adaptation strategies. Strategies to enhance local adaptation capacity are therefore required to reduce climatic impacts and maintain regional stability in oil production. At the same time, oil palm offers several opportunities to mitigate the portion of global greenhouse gas emissions that are directly dependent upon land use and land-management techniques. This chapter reviews issues relating to impacts of climate change with special emphasis on adaptation and mitigation strategies for climate-resilient oil palm production. Adaptation and mitigation strategies in oil palm could be carried out to alleviate the potential negative effects of climate change. However, important synergies need to be identified as mitigation strategies may compete with local agricultural practices aimed at maintaining production. The specific research priorities for oil palm under Indian conditions to combat climate change have also been highlighted.

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18.1 Introduction

Among the most important agricultural crops in the tropics is oil palm. Palm oil is used in a wide range of products and an important source of vegetable oil (Corley 2009) and is increasingly used as a feedstock for biofuel production (Henderson and Osborne 2000; Basiron 2007; Koh 2007). Oil palm is one of the highest edible oil yielding perennial crop that can yield 4–6 t ha^{-1} $year^{-1}$ (crude palm oil) and 0.4–0.6 t ha^{-1} $year^{-1}$ (palm kernel oil) from 3rd to 25th year of its productive life span. Globally, oil palm cultivation is centered in the tropics with highest levels of production in Indonesia and Malaysia (Basiron 2007). Both Indonesia and Malaysia are located in global biodiversity hotspots (Myers et al. 2000), so expansion in these areas is likely to have a large negative impact on biodiversity at the global scale (Sodhi et al. 2010). Various expert committees constituted by Ministry of Agriculture, Government of India, have identified 1.036 million ha in 14 states of the country as suitable for oil palm cultivation. About 80% of the area identified is located in the states of Andhra Pradesh, Karnataka, and Tamil Nadu grown under irrigated conditions. Till 2012, an area of 210 thousand ha could be covered in different states. The yields obtained by the progressive farmers of different oil palm-growing states in India range between 20 and 30 t FFB ha^{-1} $year^{-1}$. If concerted efforts are taken to bring 1 million ha under oil palm, in the identified potential areas, it would be possible to get 3–4 MT of palm oil and 0.3–0.4 MT of palm kernel oil within two decades.

According to the Third Assessment Report of Intergovernmental Panel on Climate Change (IPCC), it was found that average surface temperature of the earth has increased by 0.6°C over the twentieth century. The sea level rise has also been estimated at a rate of 1–2 mm annually during the last century. It further forecasts that globally averaged surface temperature would rise by 1.4–5.8°C and the global mean sea level may rise by 0.09–0.88 mm during 1990–2100 (UNIES 2007). IPCC has already forecasted that in the coming decades, agriculture worldwide will have to face negative aspects of this changing climate. It is anticipated that the effects on crop yields in the mid- and high-latitude regions would be less adverse than in low-latitude regions. Decrease of potential yields in warmer areas is likely to be due to shortening of crop growth period, decrease in water availability due to higher rates of evapotranspiration, and poor vernalization (Chattopadhyay 2005).

Due to climate change, the increase in temperature and variability in rainfall pattern could lead to development of abiotic stresses like heat, drought, and flooding. These stresses could occur in varying degrees coinciding with different growth and phenological phases of crops, in turn affecting their productivity and quality. Hence, timely and appropriate measures to overcome negative impacts of climate change on oil palm need to be initiated. In this chapter, the potential impacts of high temperature, water stress, and elevated CO_2 on oil palm and possible adaptation strategies to overcome these impacts are discussed.

18.2 Climate Change and Oil Palm

The ideal climatic requirements for oil palm are:

(a) Annual rainfall of 2,000 mm or greater, evenly distributed, without a marked dry season, and preferably at least 100 mm in each month
(b) Mean maximum temperature of 29–33°C
(c) Mean minimum temperature of 22–24°C
(d) Relative humidity above 45%
(e) Low vapor pressure deficit
(f) Sunshine of 5–7 h day^{-1} in all months
(g) Solar radiation of 15 MJ m^{-2} day^{-1}

A changing climate would affect oil palm plantations in many ways, with either benefits or negative consequences dominating in different agricultural agroclimatic regions. However, the factors that prevail regionally may change over time, as gradual and possibly abrupt climate changes develop in this century. Rising atmospheric CO_2 concentration, higher temperature, changing patterns of precipitation, and altered frequencies of extreme events will have significant effects on oil palm production, with associated consequences for water resources and pest/disease distributions.

18.2.1 Precipitation

The climatic models predict a change in precipitation by 5–25% over India by the end of the century with more reductions in winter rainfall than summer monsoon leading to droughts during summer months. The major effects of global climate change on crop water relations are likely to occur due to more erratic rainfall patterns and unpredictable high temperature spells. The effect of drought on oil palm growth can be divided into five stages (Lubis et al. 1993). During the first stage, i.e., when water deficit is less than 200 mm year^{-1}, palms do not show any serious problem. The second stage occurs when water deficit is 200–300 mm year^{-1} and symptoms like sticking of frond and immature leaves together and may not open. The old fronds become defective also. The third stage occurs when water deficit is 300–400 mm year^{-1} and common symptoms are number of stick and unopened leaves increases to 4–5 and number of defective old fronds will be seen in 1–1.5 spirals and fronds become dry. Subsequently when water deficit increases to 500 mm year^{-1}, young fronds will not open and leaf bud cracks, becomes defective, and breaks.

The Deli origin showed more tolerance when crossed with palms from Tanzania, Yangambi, and La Mé populations. Observations on root system of several oil palm families showed that tolerant crosses have a better-developed root system than susceptible crosses. Stomatal opening, leaf water potential, and membrane breakdown can be considered as possible selection criteria for drought tolerance in oil palm (Cornaire et al. 1989). In oil palm, leaf starch is hydrolyzed during dry season, and there is an increase in soluble sugar concentration (Adjahossou and Silva 1978). Accumulation of large amounts of proline contributes to osmotic adjustment and serves as cytoplasmic osmotic balance for potassium accumulation in the vacuole.

Moisture stress suppresses female inflorescence formation and increases abortion of female inflorescences. The inadequate water supply to meet such high evapotranspiration demand during dry period would severely affect sex differentiation and subsequent inflorescence development process which will eventually reduce the ultimate yield. An irrigation trial on a semicommercial scale in a dry area has achieved 38.8 t FFB ha^{-1} year^{-1} at the third year of irrigation as compared with only 14.1 t FFB ha^{-1} year^{-1} without irrigation. At 8–10 years old, the irrigated palms could sustain a yield of 30–35 t FFB ha^{-1} year^{-1} as compared with 16–18 t FFB ha^{-1} year^{-1} of nonirrigated palms (Foo 1998).

Screening of African dura germplasm for drought tolerance based on physiological markers has been done in India (Mathur et al. 2001; Suresh et al. 2004, 2008a, 2010). Based on these results, superior drought-tolerant duras have been identified. ZS-1 was the most drought-tolerant dura compared to that of other duras, while TS-9 was most susceptible one. Studies on membrane susceptibility indices (MSI) indicated that ZS-2 recorded highest value closely followed by TS-9 indicating their better tolerance to drought (Suresh 2010). Fourteen dura (Africa) × pisifera crosses were screened for drought tolerance in nursery by undertaking studies on membrane stability indices (MSI). Highest MSI was recorded in 34CD × 110P closed followed by 124CD × 17P and 66CD × 129P, indicating their better tolerance to drought. 254CD × 14P and 435CD × 14P recorded lower MSI indicating their poor tolerance to drought.

Suresh et al. (2012) studied genotypic variations in leaf water potential, gas exchange parameters, and chlorophyll fluorescence in five oil palm (*Elaeis guineensis* Jacq.) *tenera* hybrids at nursery, which indicated that at 24 days of imposition of water stress, highest leaf water potential was observed in 913 × 1988 which did not differ significantly with that of 1425 × 2277 and 7418 × 1988. Photosynthetic rate and stomatal conductance were significantly decreased in all hybrids due to water stress. There was a reduced apparent electron transport rate in 7418 × 1988 and 1425 × 2277 at 12 days of rehydration indicating its lesser tolerance to water stress. Highest non-photochemical quenching was observed in 7418 × 1988 after rehydration indicating its better adaptation to counter excess light energy produced due to low photosynthesis.

To understand plant stress responses in the form of sap flux and transpirational adjustments made by oil palm under Indian conditions, sap flow studies have been undertaken (Suresh et al. 2006; Suresh and Nagamani 2007), and results revealed that sap flux increased gradually from 9.00 AM reaching a peak during 1.00 to 2.00 AM and decreased as day progressed. Evapotranspiration and vapor pressure deficit also showed similar trend as that of sap flux. Seasonal variations in sap flux indicated higher sap flux during February and March and lower flux during May and June. The lower flux during dry months could be due to closure of stomata after midday as atmospheric vapor pressure deficit increased.

18.2.2 Temperature

Oil palm, being an equatorial crop, demands high temperature for its growth and yield. The climate projection studies indicate a general increase in temperatures in the order of 3–6°C over the base period average, depending on the scenario, with more warming in northern parts than southern parts. Phytotron studies indicated that best growth of oil palm was at 32/22 (mean 27°C). The next level with a mean temperature of 22°C gave only slightly slower growth. At a mean temperature of 17°C, it was only half of the best and very little growth occurred at a mean temperature of 12°C (17/7). It is however difficult to separate the effect of minimum and maximum temperature on growth and yield of oil palm. The best mean temperature range is 24–28°C, although palms at high elevation or at the geographical limit of about 15°N may be growing with mean minimum temperatures of less than 20°C for part of the year.

Higher temperatures can reduce or even halt photosynthesis, prevent pollination and anthesis, and decrease number of female inflorescences, abortion of bunches leading to bunch failure. As temperature rises, photosynthetic activity in oil palm increases until the temperature reaches 20°C. The rate of photosynthesis then plateaus until temperature reaches 35°C, where it begins to decline and at 40°C, photosynthesis ceases completely. High temperatures can also dehydrate oil palm. When oil palm folds its leaflets to reduce exposure to the sun, photosynthesis is reduced. When the stomata on abaxial side of leaflets close to reduce the transpiration load, CO_2 uptake is also reduced and thereby photosynthesis. Diurnal variations in oil palm under irrigated conditions also explain the sensitivity of stomata leading to decreased photosynthetic rates after 10.00 AM due to increase in ambient and leaf temperatures. Higher temperature (>38°C) might cause early ripening of bunches in the same whorl of palm (pseudo-ripening) during summer (1–2 weeks) leading to drastic reduction in oil extraction rates (<8%). The effect of any kind of stress (temperature/water deficits) on oil palm is revealed 1.5–2 years later on bunch yield. Oil palm being a perennial crop, there is limited scope for scheduling crop calendar.

18.2.3 Atmospheric Carbon Dioxide Concentration

Though increased CO_2 enhances the productivity of the C_3 plants in the arid regions of India, the increase in temperature may offset the beneficial effects of CO_2. Observations on oil palm CO_2-enriched seedlings indicated increased photosynthetic rate (12 folds) attributed to higher intercellular CO_2 level, decreased both stomatal conductance and transpiration (3 folds), and water use efficiency (4 folds) as compared to the control. Hence, CO_2 enrichment technique for the tropical lowlands under the greenhouse prototype controlled environment is technically feasible and has a great application potential in the seedling/nursery industry (seedlings and advanced planting materials), for production research and development study, and in the climate change impact analyses for possible enhanced bioproductivity and income generation (Hawa 2006).

However, CO_2 imposed a very marked effect on growth and leaf gas exchange parameters although all the variables measured did not differ significantly when palms were exposed to 800 and 1,200 μmol, mol^{-1} of CO_2. Exposing seedlings to higher (800 μmol mol^{-1}) CO_2 concentration resulted in higher total biomass, net assimilation rate, relative growth rate, plant height, frond number, basal diameter, and total leaf area compared to the controlled seedlings. Further increase in CO_2 concentration (1,200 µmol mol^{-1}) saturated the quantum efficiency of PSII. Total chlorophyll content and stomata density were found to be reduced. Upon enrichment, net photosynthesis and water use efficiency increased, but there was a reduction in stomata conductance and evapotranspiration rate. Increase in water use efficiency under increased CO_2 concentration implied that plant could use less water per unit carbohydrate produced especially when undergoing stress. Seedlings treated with high CO_2 increased their apparent quantum yield and maximum photosynthetic capacity, but light compensation point was reduced.

Various studies have suggested that many C_3 plants respond to CO_2 enrichment to a greater extent than at ambient CO_2 as a result of increased quantum yields (Hanstein and Felle 2002). A small increase in quantum yield may increase daily carbon gain under low light conditions (Kiirats et al. 2002). In oil palm, elevated CO_2 increased apparent quantum yields in 800 and 1,200 µmol mol^{-1} CO_2 treatments. Light response curve analysis of oil palm seedling had shown that CO_2 enriched seedlings had reduced their dark respiration rate by 43% to 70% through enhancement of their saturated photosynthetic capacity and apparent quantum yield by 52% to 78% and 15% to 62%, respectively. The enhancement of light compensation point and quantum yield signifies direct inhibition of the activity of key respiratory enzymes under elevated CO_2 (Drake et al. 1997). This result has been supported by Henson and Haniff (2006) who reported productivity or dry matter production of plants would increase if respiration could be minimized without affecting gross assimilation or if gross assimilation could be increased without increasing respiration. Usually, compensation irradiance is reduced while quantum efficiency is increased in plant under elevated CO_2 (Vivin et al. 1995). The same result was also observed by Kubiske and Pregitzer (1996) with red oak seedlings grown at elevated CO_2 in shaded open top chamber.

In oil palm, it was found that enrichment with high levels of CO_2 has enhanced the leaf gas exchange of oil palm seedlings. The upregulation of photosynthetic rate may be due to increased leaf intercellular CO_2 concentration (Ci) that could also be related to increase in the thickness of leaves achieved under elevated CO_2 that contains high photosynthetic protein especially Rubisco (Ramachandra and Das 1986). The latter might also upregulate several enzymes related to carbon metabolism which simultaneously increase the Ci (Anderson 2000). In oil palm, high photosynthetic rate under elevated CO_2 could be due to more efficient net assimilation resulting from extra carbon fixation as exhibited by high Ci which is related to increased thickness of mesophyll layer, mainly due to increased palisade layer (Lawson et al. 2002).

In oil palm, the increase in photosynthesis might be justified by reduced light compensation point and dark respiration rate in the plant enriched with high CO_2 having enhanced apparent quantum yield and net assimilation rates (Kubiske and Pregitzer 1996). Despite increases in A and WUE, stomatal conductance of oil palm seedlings enriched with high levels of CO_2 decreased, as levels of CO_2. The decreased g_s simultaneously reduced the transpiration rate of plants under elevated CO_2 (Raschke 1986; Lodge et al. 2001; Lawson et al. 2002). Nitrogen content was influenced by the application of CO_2 levels to the seedlings. As the levels of CO_2 increased from 400 to 1,200 µmol mol^{-1}, nitrogen content was found to be reduced. The decrease in nitrogen content with increasing CO_2 levels has been reported by Porteaus et al. (2009). Several researchers attributed this phenomenon to decreasing uptake of nitrogen as transpiration rate was decreased due to reduction in stomata conductance under elevated CO_2 level (Conroy and Hawking 1993).

18.2.4 Pests and Diseases

Pests associated with specific crops may become more active under climate change (Coakley et al. 1999; IPCC 1996). Increased use of agricultural chemicals might become necessary, with consequent health, ecological, and economic costs (Rosenzweig et al. 2002a, b; Chen and McCarl

2001). Warmer temperatures may increase the development rates of some insect species, resulting in shortened times between generations and improved capacity for overwintering at northern latitudes. Further some insect populations may become established early in the growing season, during more vulnerable stages of the crop.

Warmer winter temperatures favor the increase in insect pest populations of oil palm. Overall temperature increases may also influence crop pathogen interactions by speeding up the pathogen growth rates, which increases reproductive generations per cycle, decreasing pathogen mortality rate due to warmer temperatures and by making the crop more vulnerable. Incidence of slug caterpillar in oil palm occurs during the summer months (April–May) in Andhra Pradesh, causing severe defoliation and reduction in yields. Incidence of bunch end rot is noticed during summer, wherein a group of distal fruits abort and are delineated from the basal portion of the bunch and 25–50% of the bunch gets affected. Correlation studies of weather parameters with the manifestation of spear rot disease in oil palm indicated a positive correlation of the disease with rainfall and number of rainy days and a negative relationship with average maximum temperature. Higher incidences of spear rot and bud rot diseases were noticed during rainy seasons. Elevated CO_2 indirectly modify insect–crop relations, via an increase in the C–N ratio in crop leaves, which renders them less nutritious per unit mass and would stimulate increased feeding by insects, leading to more plant damage (Lincoln et al. 1984; Salt et al. 1995).

18.3 Climate Change Impacts: Case Studies

Research on the *El Niño*–Southern Oscillation (ENSO) phenomenon has found that this ocean–atmosphere interaction especially in tropical Pacific Ocean dramatically affects weather and climate in the nations bordering Pacific Ocean and even beyond the subtropics. *El Niño* and *La Niña* phases do occur in these regions due to this phenomenon. The Southern Oscillation Index (SOI) is calculated from monthly or seasonal fluctuations in the air pressure difference between Tahiti and Darwin, and this numerical index is a good approximation of the occurrences of *El Niño* and *La Niña*. SOI values exceeding (−10) for several months generally indicate *El Niño* episodes, while SOI of more than (+10) show *La Niña* events (Samah and Sootyanarayana 2000).

18.3.1 Malaysia

Oil palm is a tree crop, and the roots extend deep into the soil and cover a wide area laterally. In addition, it is well documented that the effect of soil moisture deficit is only revealed 1.5–2 years later on oil palm bunch yield by increasing the production of male inflorescences compared to that of female flowers and by inducing abortion of female inflorescences during their period of maximum growth. FFB residuals plotted against average derived Southern Oscillation Index (SOI) showed a random scatter indicating no relationship between oil palm FFB yield and the assumed climate water availability parameter SOI. The derived SOI indicator was imperfect as it did not match the particular yield sensitive development phase of oil palm (Samah and Sootyanarayana 2000).

The 1981 and 1982 episodes of *El Niño* in Malaysia have resulted in 21% loss, the following year, while the 1990 episode had resulted in a more than 10% yield loss in 1991. The most severe *El Niño* episode of 1997 resulted in yield losses of 16.8%. The resultant water stress, especially during 1997, resulted in a significant reduction in productivity (CGPRT Monograph 2002). Oil extraction rates have experienced varied fortunes due to climate change. In both Indonesia and Malaysia, the worst effects of the *El Niño* reduced the OER in the late 1990s (Carter and Jackson 2007).

La Niña causes increased rainfall in northern Australia, Kalimantan, Indonesia, Papua New Guinea, and Malaysia. Increased rainfall is good for oil palm, which requires at least 2,000 mm of rain a year or more. This would help oil palm trees to recover from the after effects of *El Niño*. In fact, palm oil yields across Indonesia and

Malaysia started to recover, and production started to equal pre-*El Niño* levels. However, excessive rainfall is detrimental as yield is significantly affected. It was reported that flood-related problems in southern Malaysia had decreased the production of crude palm oil to 1.1 million metric ton or 26.3% during December 2006 (Greenall 2008).

18.3.2 Columbia

Due to its perennial nature, oil palm reacts negatively to unfavorable climatic conditions, viz., evapotranspiration is reduced, leaf opening is delayed (first stage), and sexual differentiation is affected (reducing the proportion of female productive vs. male nonproductive inflorescences). Water is fundamental in sexual differentiation, development of central arrows, flowering, and fruit production. More female inflorescences are found when the level of solar radiation is good. If any of these requirements are not met, the final production will be reduced during the first and consecutive harvests. Higher (lower) production was observed during and 6 months after periods of enhanced (reduced) precipitation in oil palm due to the fruit's accelerated (slowed) maturity (final stages). The same pattern was also observed in the period that corresponds to the initial stages of bunch formation (27 months) and central arrow development (17 months), when the water supply in the soil became the most important factor for future production (Cadena et al. 2006).

In general, the region of Tumaco had a suitable HAI since rainfall exceeded evapotranspiration. However, for the years with higher drought probabilities (*La Niña* events), reduced precipitation in the second semester is accentuated. This deficit could be reflected in the next 3 year's production, which corresponds to bunch development. High (low) HAI values become important to the plant 17–27 months later, owing to a preservation (consumption) of rainwater in soils. This is the period in which the central arrow develops, which means that inadequate water supply during this stage will be reflected in low production two years later. Climatic variations had important effects on oil palm production during different stages of the plant's life cycle. The 1997/1998 *El Niño* was highly favorable to oil palm production in all its development stages, having a maximum cross-correlation with production 2.6 years later (2000). The 1999/2000 *La Niña* had the highest negative impact since it occurred during the second semester of the year, causing droughts and reduced oil palm production during 2002 (Cadena et al. 2006).

18.3.3 India

Most of the oil palm-growing areas lie on the eastern and western coast of India. The mean temperature in coastal Andhra Pradesh (East Coast) and Kerala (West Coast) from 1901 to 2006 reveals an increase of 0.8°C and 1.2°C, respectively. The rainfall pattern from 1901 to 2006 shows an increase of 3.47% in the coastal Andhra Pradesh and 2.58% in Kerala. A perusal of the mean temperature in Andhra Pradesh indicates that there has been an increase of 1.6°C and 1.59°C in East and West Godavari districts, respectively, during 1971–2002 (Suresh and Kochu Babu 2010).

As crop models for oil palm are lacking under Indian conditions, correlations between FFB yields, and mean temperatures were worked out in the major oil palm-growing areas—East and West Godavari districts of Andhra Pradesh and OPIL plantations of Kerala. The mean temperatures and FFB yields of oil palm plantations in East Godavari district of Andhra Pradesh from 1998 to 2007 indicate that there has been an increase of 0.3°C in temperature during the above period. FFB yields did not vary among the different years, which indicate that mean air temperature had little effect on it. As oil palm plantations in Andhra Pradesh are mostly grown under irrigated conditions, management of nutrients and water would be the key factors in determining FFB yields (Suresh and Arulraj 2010).

A perusal of the mean temperatures and FFB yields of oil palm plantations in West Godavari district of Andhra Pradesh from 1999 to 2007 indicates that there has been an increase of

0.61 °C during the period. There has been a weak correlation between mean temperature and FFB yields. The increase in FFB yields over the years is mainly due to better management of water and nutrients. Correlation studies between FFB yields of East and West Godavari districts of Andhra Pradesh and their mean temperature (1998–2007) also indicate a weak relationship between them. The effect of mean temperature on the average FFB yields (1988–2005) of oil palm plantations (OPIL) of Kerala under rainfed conditions indicates that the relationship between them is very weak and a probable dependence on rainfall (Suresh and Kochu Babu 2010; Suresh and Arulraj 2010).

18.4 Adaptation Strategies

Cumulative past emissions have already committed the planet to a certain degree of climate change and associated impacts over the coming decades regardless of what local, regional, and global actions are taken and which policy recommendations are adopted to slow anthropogenic emissions of greenhouse gases and thus to reduce the magnitude of climate change. Climate actions taken today will determine how such changes will further evolve in the second half of this century. Recent observations of increased frequency of climate extremes worldwide, as well as shifts in eco-zones, might be an indication of global warming-related changes already under way (IPCC 2001a, b, c; Milly et al. 2002; Root et al. 2003). Sectoral adaptation is thus very likely in the future and integral to the study of climate change impacts on agriculture (IPCC 2001a, b, c; Smit and Skinner 2002; Smith et al. 2003).

Adaptation in agriculture is the norm rather than the exception. In addition to changes driven by several socioeconomic factors like policy frameworks and market conditions, farmers always had to adapt to the vagaries of weather on weekly, seasonal, annual, and longer timescales. The real issue in the coming decades will be the degree and nature of climate change compared to the adaptation capacity of farmers. If future changes are relatively smooth, farmers may successfully adapt to changing climates in the coming decades by applying a variety of agronomic techniques that already work well under current climates, such as adjusting the timing of planting and harvesting operations, substituting cultivars, and modifying or changing their cropping systems. Adaptation strategies will vary with agricultural systems, location, and scenarios of climate change considered.

18.4.1 Development/Shifting to Heat/Drought-Tolerant Hybrids

The selection of crops and cultivars with tolerance to abiotic stresses like drought, flooding, high salt content in soil, high temperature, pest, and disease resistance allows utilizing genetic variability in new crop varieties if national programs have the required capacity and long-term support to use them. To strengthen capacity of developing countries to implement plant breeding programs and develop locally adapted crops, FAO and other like-minded institutions have started Global Initiative on Plant Breeding Capacity Build initiative during June 2007 to implementation of Article 6 of the Treaty for supporting the development of capacities in plant breeding. It emphasizes conserving diversity, adapting varieties to diverse and marginal conditions, broadening the genetic base of crops, promoting locally adapted crops and underutilized species, and reviewing breeding strategies and regulations concerning variety release and seed distribution. FAO's work on adapted crops includes decision-support tools such as Ecocrop to identify alternative crops for specific ecologies.

18.4.2 Soil and Land Management

Adaptation to climate change for oil palm cropping systems requires a higher resilience against both excess of water (due to high-intensity rainfall) and lack of water (due to extended drought periods). A key element to respond to both problems is soil organic matter, which improves and stabilizes the soil structure so that the soils can absorb higher amounts of water without much surface runoff, which could result in soil erosion and flooding. Soil organic matter also improves the water absorption capacity of the soil during extended drought.

Low tillage and maintenance of permanent soil cover are to be promoted that can increase soil organic matter and reduce impacts from flooding, erosion, drought, heavy rain, and winds. Among areas which can be explored are conservation agriculture, organic agriculture, and risk-coping production systems. Intensive soil tillage reduces soil organic matter through aerobic mineralization and low tillage, and the maintenance of a permanent soil cover through crop residues or cover crops increases soil organic matter. Conservation agriculture and organic agriculture are promising adaptation options in oil palm for their ability to increase soil organic carbon, reduce inorganic fertilizers use, and reduce on-farm energy costs.

18.5 Mitigation Strategies

While oil palm production stands to be affected by projected climate change, it has been a source of greenhouse gases to the atmosphere, thus itself contributing to climate change. Clearing and management of land for food and livestock production over the past century was responsible for cumulative carbon emissions of about 150 gt C, compared to 300 gt C from fossil fuels (LULUCF 2000). At present, agriculture and associated land use changes emit about a quarter of the carbon dioxide (through deforestation and soil organic carbon depletion, machine and fertilizer use), half of the methane (via livestock and rice cultivation), and three-fourths of the nitrous oxide (through fertilizer applications and manure management) annually released into the atmosphere by human activities. Modifying current management of agricultural systems could therefore greatly help to mitigate global anthropogenic emissions. Many see such activities in the coming decades as new forms of environmental services to be provided to society by farmers, who in turn could additionally increase their income by selling carbon-emission credits to other carbon-emitting sectors.

18.5.1 Carbon Sequestration

Absorbing CO_2 from air and injecting it into the biomass is the only practical way of removing large volumes of greenhouse gases from the atmosphere. The processes that remove carbon from the biosphere are termed as carbon sequestration. Standing crops like oil palm serve as net accumulators of carbon, thereby offsetting carbon emissions, arising mainly from fossil fuel consumption. With respect to the net fixation or sequestration of carbon, there are possibilities of financial gains by developing countries like India through carbon trading under the terms of Kyoto Protocol. With more than 2.0 lakh hectares of oil palm plantations in India, oil palm seems to be a prime candidate for storing carbon and is also eligible for Clean Development Mechanism (CDM). To qualify as a CDM project, projects must be large and are expected to save millions of tons of greenhouse gases per year. Landmass of about 1,000 ha would need to be assembled for a project. In India, where land holdings are small, a number of plantations would need to be assembled to make it large.

Global carbon storage by oil palm is estimated at 74 Mt C $year^{-1}$ for 12 m ha due to its high annual biomass productivity (50 t DM ha^{-1} $year^{-1}$) compared to that of coconut (28 t DM ha^{-1} $year^{-1}$). The amount of carbon sequestered by eleven-year-old oil palm hybrids under irrigated conditions ranged between 17.98 and 35.44 t C ha^{-1} with Papua New Guinea and Ivory Coast hybrids sequestering the highest and lowest carbon contents, respectively. Among the Palode hybrids, the carbon sequestered ranged from 20.26 (P12 × 313) to 26.05 t C ha^{-1} (P12 × 266). The carbon sequestered by the ASD Costa Rican hybrids was between 20.54 (ASD Deli × Ghana) and 35.44 t C ha^{-1} (ASD Deli × Ekona). The two Ivory Coast hybrids sequestered carbon between 17.98 and 28.73 t C ha^{-1} (Suresh and Kochu Babu 2008). Another study under irrigated conditions indicated that the carbon contents in the different fronds of a mature palm ranged from 0.413 to 1.314 kg. The carbon contents were low in the younger leaves and did not show any pattern among the middle and lower whorls (Suresh et al. 2008).

18.5.2 Zero Burning

Zero burning involves chipping or stacking the material cleared from a site being prepared for oil palm cultivation between the palm rows and leaving it to decay. This technique mitigates carbon dioxide emissions released from burning vegetation to clear land; however, it should be mentioned that unless a significant portion of the biomass from land clearing is used to manufacture wood products with a long useful life (instead of simply decaying), mechanical land clearing methods will only have a short-term effect on carbon emissions. Zero burning is now a well-established policy adopted by the majority of reputable estate companies to clear their land in Indonesia. Nevertheless, there remains a clear gap between stated company policies of zero burning and the interpretation of middle management on the ground and contractors engaged to clear land on behalf of oil palm companies (Sargeant 2001). Satellite imagery continues to prove that large-scale estates use fire to clear land. Estate companies still continue to use fire to clear land because it is easier to flick a match than to undertake manual land clearing. Many companies also continue to use fire rather than zero burning because it is thought to be a cheaper method of clearing land at the onset. This was confirmed by Guyon and Simorangkir (2002) who undertook extensive economic analysis on the costs and benefits of zero burning versus burning in commercial oil palm plantations.

18.5.3 Improve Water Management in Existing Oil Palm Plantations

Appropriate drainage system must be designed to remove excessive water in heavy soils but maintain the water table at a depth of 0.5–0.7 m from the soil surface to prevent excessively rapid depletion of the soil layer in existing oil palm plantations. A good drainage system will not only retard oxidation but also improve the yields and performance of the palms. If the drainage system is not good, palms tend to fall over and stem becomes bent. This results in an uneven canopy and reduced yield. It also makes harvesting and other field operations difficult (Kee et al. 2003).

18.5.4 Reduce Chemical Inputs to Reduce Other Greenhouse Gas Emissions

Chemical inputs, such as fertilizers, pesticides, and herbicides, release a host of greenhouse gases (carbon dioxide, nitrous oxide, and methane) into the atmosphere. It is important to consider the emissions of other greenhouse gases resulting from chemical inputs applied to oil palm plantations as the global community ultimately aims to identify strategies that can mitigate global warming. Oil palm is one of the largest consumers of inorganic fertilizer nutrients in Southeast Asia (Hardter and Fairhurst 2003). A typical oil palm plantation planted on mineral soils requires around 1,114 kg/ha of nutrient inputs over the first 5 years of planting. The most relevant nutrient input from a climate point of view is nitrogen. A typical oil palm plantation planted on both mineral and peat soils requires around 354 kg/ha of nitrogen over the first five years. This is usually applied with the use of a number of nitrogen-based fertilizers—NPK (ammonium nitrate), ammonium sulfate, and urea. In addition to this, pesticides and insecticides are also used liberally in oil palm plantations to control fungal diseases, weeds, and other pests commonly found in oil palm plantations (rhinoceros beetle). All these pests and diseases are more prevalent in oil palm plantations that use zero burning rather than fire to clear land. In the short term, zero burning can also require higher fertilizer requirements during the early years (0–2) because fire is an efficient means to convert nutrients contained in the standing biomass into minerals. However, mechanical land clearing may result in lower fertilizer application because the nutrients from decaying wood debris left after zero burning are released very slowly into the soil (Guyon and Simorangkir 2002).

Integrated pest management may be practiced, which involves the intelligent use of cultural, biological, and physical methods as needed to help minimize the requirement for pesticides. For instance, the rhinoceros beetle can be contained using a combination of cropping practices (pulverization, shredding the vegetation debris, and covering it with leguminous cover crops) or with biological controls, such as pheromone traps.

Integrated Pest Management practices are improving all the time but are currently considered to be more expensive than traditional pest management methods that utilize pesticides. Nevertheless, managing pests and diseases solely through heavy use of pesticides can potentially have significant environmental costs, including the runoff of pesticides into watercourses and the incidental killing of nontarget species.

Composting of Empty Fruit Bunches (EFB) and Palm Oil Mill Effluent (POME) enables the mills to achieve zero waste management while at the same time producing organic compost could successfully substitute chemical fertilizer (partially) in the plantations, enabling substantial savings and a sustainable business model. Biomass usage for energy production would displace fossil fuel-based energy in mills. Palm oil can be used either as palm biodiesel or burning palm oil directly as biofuel to replace fossil fuel so as to reduce carbon dioxide generation. The oil palm biomass is normally used as fuels for boilers to generate power.

18.6 Future Research Strategies

As oil palm has been introduced into India in the late eighties and the establishment of Directorate of Oil Palm Research only during 1995, research on oil palm on these aspects is very scanty, and hence, there is urgent need to focus more on the impact of climate change on the basic physiological aspects of the crop. The specific research priorities for this crop are as follows:

- To phenotype drought, salinity, and high temperature tolerance traits in oil palm tenera hybrids (indigenous and exotic) along with interspecific hybrids, dura and pisifera parents using phenomics platform.
- To quantify CO_2 flux, energy budget, and water transfer within an oil palm plantation using eddy covariance studies. There is an urgent need to collect available data on soil and carbon content in oil palm plantations and for possible precursor situations before establishment and understand the sequestration of carbon in soil and plants with careful attention to the Kyoto protocol for getting carbon permits. Studies on carbon sequestration and quantification of carbon flow and budget in oil palm agroecosystem will definitely help in this regard.
- To understand seasonal and annual variations in vegetative and reproductive growth, phenology, and yield components in response to climatic variables. Oil palm is highly sensitive to drought and is strongly affected by climatic anomalies such as *El Niño* in Southeast Asia. Intra- and interannual yield variations are very high and are difficult to interpret as physiological causes for general seasonal variation are largely unknown. Annual FFB production is continuous but generally shows marked seasonal peaks which cannot be explained either by carbon assimilation or by phenology. Very little information is known about endogenous or environmental control of periodic events in oil palm. The effect of climatic variability on yield components is complex due to longer developmental duration of female inflorescences and larger number of inflorescences having different developmental stage on the plant at a given point of time. The effect of drought on yield components occurs with long time lags as drought-sensitive processes like sex determination and abortion take place months or years before maturity of a given bunch. Relationship between environmental variables and vegetative and reproductive growth parameters can be worked out along with time lags. The results generated can be used to predict them with models.
- To assess and quantify impact of CO_2 and temperature in oil palm using CO_2 enrichment studies. A better understanding of the effects of elevated CO_2 and changes in soil water content on gas exchange processes and plant water relations could help in knowing its capacity to withstand drought. Experiments can be planned to understand the effect of elevated CO_2 on growth and various physiological processes in oil palm. Experiments can be undertaken to investigate effect of different CO_2 concentrations on seedling growth, leaf gas exchange characteristics, and nutrient status in oil palm hybrids belonging to different sources.

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Floriculture, a Viable Option of Diversification in the Light of Climate Change

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Abstract

Flowers' being most sensitive part of a plant is expected to be affected most by the climate change. For increased CO_2 concentrations, most of the flower crops are responding positively by the enhanced rates of photosynthesis and biomass production. Carbon dioxide levels of 800–1,800 ppm have proven to be optimal for the majority of flower crops grown under protected cultivation. Crop production is sensitive to variability in climate in general and temperatures in particular. Temperature is a major factor for the control of plant development, and warmer temperatures are known to shorten development stages of determinate crops leading to reduced yield of a given crop. Early flowering and maturity have been observed to be associated with warmer (spring) temperatures. Floriculture, as an intensive farming under protected conditions, is often not affected by the outside temperatures. With increasing climatic vagaries, flower crops grown under protected conditions may prove to be one of the safest cultivations to overcome the climate change effects.

19.1 Introduction

Floriculture in India has made rapid strides both in domestic and in international market in the last couple of decades. About 182.90 thousand ha of area is under floriculture producing 1.0206 million of loose flowers and 6.6671 billion numbers of cut flowers during 2009–10 (Table 19.1). A recent estimate of National Horticulture Board puts the area under floriculture during 2010–11 at 191,000 ha with a production of 1.031 million of loose flowers and 6.9027 billion of cut flowers.

The floriculture industry comprises the cultivation and trade of cut and loose flowers, potted plants, foliage and fillers, bedding plants and dried flowers under open field as well as under protected conditions. Potted plants and cut flowers contribute almost 80% share in the world trade, whereas, in India, dry flower contributes a major share to the overall export trade in floriculture. Other segments like fillers, seeds and planting material, turf, allied grower industries

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Table 19.1 Area and production of flower crops in different states of the country (2009–10)

State/UT'S	Area ('000 ha)	Production Loose ('000 MT)	Cut (millions)
Andaman and Nicobar	0.0	0.3	–
Andhra Pradesh	21.4	130.3	620.20
Arunachal Pradesh	1.2		286.00
Assam	–	–	–
Bihar	0.2	2.3	1.10
Chhattisgarh	4.1	13.5	0.0
Delhi	5.5	5.7	103.80
Gujarat	12.5	49.5	506.30
Haryana	6.2	60.3	108.40
Himachal Pradesh	0.7	0.6	60.50
Jammu and Kashmir	0.1	0.2	6.63
Jharkhand	1.6	22.0	171.10
Karnataka	27.0	203.9	586.00
Kerala	–	–	–
Madhya Pradesh	6.6	5.0	–
Maharashtra	17.5	91.1	791.40
Manipur	0.0	0.0	
Meghalaya	–	–	–
Mizoram	0.0	0.0	14.20
Nagaland	0.0	0.0	1.70
Orissa	7.1	25.3	535.60
Pondicherry	0.3	2.4	–
Punjab	1.7	82.0	–
Rajasthan	3.3	4.9	–
Sikkim	0.2	–	20.00
Tamil Nadu	32.0	247.3	
Tripura	–	–	–
Uttar Pradesh	10.4	17.6	295.80
Uttranchal	1.3	1.0	341.40
West Bengal	21.9	55.2	2217.00
Total	182.9	1020.6	6667.14

Source: NHB Database 2011

and value-added products also contribute a share in the overall growth of floriculture sector.

Domestic market both for cut flowers and loose flowers has increased significantly owing to rapid urbanization, changes in social attitude, increase in income level and the increasing habit of 'saying it with flowers'. The per capita consumption of flowers is continuously increasing due to which the production has been increased and nontraditional areas have emerged as important players in floricultural production. Thus, it may be visualized that there would be tremendous growth in the domestic market in the coming years.

19.2 Climate Change and Floriculture

Growth and development of any plant is largely an expression of the interaction of the genotype with the environment. The environmental factors which contribute to this include temperature, duration and intensity of light, humidity and carbon dioxide. It has been found that little information is available on the interplay of these environmental factors either singly or in association with each other on the growth and flowering of various flower crops grown under open conditions.

Globally commercial floriculture unlike other agricultural crops is best practised under protected conditions wherein the climate is controlled. Studies on CO_2 enrichment in commercial flower crops like rose, lilium, carnation, chrysanthemum, anthurium, gerbera, alstromeria, etc. grown under protected conditions have yielded beneficial results. Studies on the effect of elevated temperature and interaction of CO_2 enrichment and associated rise in temperature are limited in flower crops.

In the recent past, floriculture has been considered as a viable option for diversification in agriculture. Availability of rich diversity of ornamentals and varied agro-climatic conditions offers floriculture as a feasible option of diversification in agriculture even in the era of climate change. Crops like tuberose, gladiolus, annual chrysanthemum, certain varieties of rose, marigold, etc. are hardy and suitable for production under wide climatic conditions to meet the huge domestic demand in the coming years. Several technologies have been developed in ornamental crops to increase the production and to reduce the production losses due to biotic and abiotic factors. If the increase in atmospheric CO_2 concentration is accompanied by an increase in air temperature, crops may shorten their growing cycle, which may offset the advantages of elevated CO_2 concentrations. There is, hence, an urgent need to work on the interacting effects of CO_2 concentration and changes in temperature on the growth and yield of flower crops grown under open field.

19.2.1 Response of Flower Crops to Elevated CO_2 Concentration

More than two decades of study on the effects of CO_2 enrichment on plants has provided a rich suite of data and understanding about a wide variety of plant responses. The data related to plant dry weight (biomass) and net photosynthetic rate as influenced by atmospheric CO_2 enrichment in number of crops is available at http://www.CO_2science.org. Initial short-term experiments demonstrated that elevated CO_2 concentrations partially alleviated the limitation of C3 (but not C4) photosynthesis by CO_2 supply and acted as a negative feedback on transpiration in both C3 and C4 species. Subsequent and often long-term experiments have shown that photosynthesis could acclimate downwards in response to CO_2 enrichment, and there is now some evidence to suggest that photosynthesis is stimulated in C4 species in response to enrichment (Ghannoum et al. 2000; Watling et al. 2000).

In species with the C3 photosynthetic pathway, high irradiance can lead to photo-inhibition. Field studies have now demonstrated that CO_2 enrichment can reduce the severity of photo-inhibition, although this effect is dependent on rubisco activity (Hymus et al. 2000). Fertilization or enrichment of air with CO_2 in commercial greenhouses has been practised for a considerable time (Rosenberg et al. 1983). Porter and Grodzinski (1985) reviewed the status of CO_2 enrichment under protected conditions and documented the enrichment procedures and benefits in flower crops.

In *Rosa hybrida*, Pan et al. (2008) studied the effects of CO_2 enrichment during morning and evening and found an increase in cut flower production in the cvs. Escimo (41.5% and 18.2%) and Black Beauty (28.4% and 19.55%), respectively. Cut flower yield of cv. Dream grown was highest with an increase of 115.9% in morning CO_2 enrichment over the control.

In oriental yellow poly-bud cut lily, CO_2 at 600 ppm could increase the stem height (about 0.57 grades) and also had a positive effect on the growth of colour bud (Shenglin 2005). Whereas, in water lily, Idso et al. (1990) reported that CO_2 enrichment at 650 ppm leads to increased net photosynthesis (49%), leaf size (18%) and whole-plant biomass enhancement (270%).

In *Hippeastrum*, Ephrath et al. (2001) conducted an experiment on the growth and development of *Hippeastrum* in response to temperature and CO_2. A significant difference in final bulb diameter was obtained between the 16°C, 22°C and 24°C treatments. The number of leaves, however, was affected by the CO_2 but not by the temperatures. Bulbs grown under elevated CO_2 had a higher flowering rate compared to ambient CO_2. Silberbush et al. (2003) found that the bulb diameter was enhanced by CO_2 enrichment and the effect was more pronounced with the use of smaller planting bulbs.

Lake and Hughes (1999) studied the effect of CO_2 on nasturtiums (*Tropaeolum majus*) and found that a 380-ppm increase in the air CO_2 concentration elicited a 35% increase in the total plant biomass. Atmospheric CO_2 enrichment did not affect flower size in this species, but total flower nectar volume produced by the CO_2-enriched nasturtiums was 2.4-fold greater than that produced by ambient grown control plants.

Likewise, Niu et al. (2000) found that yellow and primrose pansies (*Viola* × *wittrockiana*) increased their total dry weights by 10–30% in response to a 600-ppm increase in CO_2 concentration of the air, while flower size increased by 4–10%. In another study, Carvalho and Heuvelink (2001) reported that CO_2 enrichment positively influences several quality characteristics of chrysanthemums, including stem length, number of laterals, number of flowers and flower size.

More studies demonstrating similar positive effects of CO_2 enrichment on flowering have been reported. Silberbush et al. (2003), for example, grew small and large bulbs of *Hippeastrum* in greenhouses receiving CO_2 concentrations of 350 and 1,000 ppm for about 4 h/day for 233 days with different combinations of nitrogen and potassium fertilization in order to study the interactive effects of these parameters on bulb size. Their results indicated that elevated CO_2 consistently increased bulb size across all nitrogen and potassium concentrations, with initially larger bulbs yielding the greatest size of final bulbs. However, on a percentage basis, smaller bulbs were slightly more responsive to CO_2 enrichment than larger bulbs. Indeed, under optimal nitrogen and potassium fertilization, the 650-ppm increase in the CO_2 concentration increased the size of smaller and larger bulbs by about 18% and 14%, respectively, suggesting that as the CO_2 content of the air increases, *Hippeastrum* bulbs will increase their size, thus leading to enhanced bulb quality and flower (amaryllis) production.

In another study, it is reported that elevated CO_2 itself advanced flowering by a mean of 4 days, while increasing temperature as well as CO_2 advanced flowering by an additional 3 days. They also found that CO_2 was more likely to hasten phenology in long-day than in short-day plants, early- and late-flowering species did not differ in response to elevated CO_2, but the combined effect of elevated CO_2 and temperature hastened flowering more in early- than late-flowering species. In the light of several findings, Johnston and Reekie (2008) thus concluded that, with respect to time of flowering in *Asteraceae* species, the direct effect of CO_2 on phenology may be as important as its indirect effect through climate change.

The several observations presented above suggest that a CO_2-enriched world will likely to produce more and larger flowers, as well as induce other flower-related changes bearing significant positive implications for plant productivity and survival.

19.2.2 Response of Flower Crops to Temperature Variations

Plant temperature is affected by radiation energy transfer and evaporation from the plant surface. The relationship between plant growth and temperature is complex because temperature is a factor in the reaction rates of various metabolic processes. Future temperature change linked to global warming might be characterized by an asymmetry between daytime maxima and night-time minima instead of a uniform increase (Karl et al. 1991).

Table 19.2 Optimum day-n-night temperatures for quality cut flower production

Crop	Temperature (°C)	
	Night	Day
Rose	15	20
Carnation	13	18
Chrysanthemum	8	15.6
Gladiolus	15	23
Gerbera	12	16
Anthurium	18.3	23.9
Vanda, Dendrobium and Phalaenopsis	15.5	26.5
Cymbidium and Paphiopedilum	10	13
Dahlia	16	25
Tuberose	16	30

Most of the flower crops in greenhouses are grown at specified night temperature with a minimum increase of 10–15°C (Mastalerz 1977; Laurie et al. 1979). Globally, most of the flower production practised under protected conditions with optimum day-n-night temperatures (Table 19.2) especially in Western countries which are covered with snow during winters. In this way, microclimate change is already in vogue in flower crops. In India, the situation is different as the floriculture is limited to only 5–10% of total area under cultivation.

Gladiolus production at high temperatures (42–45°C) and dry air (42–45% RH) conditions resulted in low flowering percentage (54%) and the number of florets per spike (6.1) compared to 85% flowering and 8.5 florets per spike at 36–40°C and moist air (60–70% RH) (Shillo and Halevy 1976a). The rate of development is primarily affected by temperature, and as the temperature rose from end of February, the rate of growth and development also increased. The October 15 planting was most sensitive to low irradiance. Flowering of December-planted plants was unaffected (Shillo and Halevy 1976b). On the other hand, low light intensity in winter coupled with low temperatures of 1–4°C increased the occurrence of flower opening (Shillo and Halevy 1976c). Post (1952) also found that summer grown gladiolus bloomed after 60–80 days of planting whereas the winter crop took almost double time. Laurie et al. (1979) reported earliness of flowering by several weeks when the soil temperature was raised from 50°F to 65–70°F.

Amaryllis (*Hippeastrum*) cv. Apple Blossom when exposed to temperature regimes of 18/14, 22/18, 26/22 or 30/26°C (day/night), the highest quality plants were produced at 22/18°C with long days, and the plants produced at 18/14, 22/18 and 26/22°C under long- and short-day conditions were satisfactory (De Hertogh and Gallitano 2000).

In *Ornithogalum longibracteatum* and *Tulbaghia violacea* (Kulkarni et al. 2005), low temperatures resulted in poor germination in both species. Optimum percentage germination was achieved between 20°C and 30°C. It was reported that low temperatures are favourable for bulb formation and high temperatures for leaf growth.

Lilium longiflorum cv. Nellie White produced maximum number of flowers when grown at a day-night temperature regimes ranging between 10/6°C and 22/18°C, but the production was decreased at 26/22°C, and there was no production at 30/26°C (Kim et al. 2007).

Rose cv. Sonia responded to root heating with respect to plant growth, shoot width, number of leaves, breaks per branch and number and quality of flowers with a peak at about 21°C (Zeroni and Gale 1998).

In Asiatic hybrid lily, Roh (1990) studied the effect of high temperature on bud burst. Bulbs were planted in pots and placed in growth chambers at day/night temperatures of 16/13°C or 26/24°C for 14 days. Flowering was accelerated, and the number of primary buds busted was highest in cvs. Red Carpet and Cherub at 26/24°C.

In another study, Runkle (2006) found that plants respond differently to temperature partly because they have different base temperatures (Table 19.3). Plants with a base temperature of 39°F (4°C) or lower can be called 'cold-tolerant plants,' and those with a base temperature of 46°F (8°C) or higher can be called 'cold-sensitive plants.' Plants categorized by their base temperature because they differ in the way they respond to lowering of the greenhouse temperature; generally, cold-sensitive plants are more responsive to low temperature than cold-tolerant species. Lowering the greenhouse temperature below a set point may result in crop phonological stages likely to be delayed more with cold-sensitive crops. There are other factors that influence crop stages, including photoperiod and the average daily light intensity. Ideally, crops with different base temperatures should be grown in separate greenhouses with different temperature set points.

Temperature, through its effects on the rate of enzyme-mediated reactions, has profound effects on the rate of development (Minorsky 2002), and cumulative annual temperature is a good predictor of flowering time in many species (Went 1953). Experiments on warming indicated that increased temperature has a marked effect on flowering time in many, but not all, species (Price and Waser 1998; Cleland et al. 2006; Lambrecht et al. 2007). Further, it has been shown that elevated temperature has differential effects on flowering in early- and late-flowering species. Flowering was hastened it in tall grass prairie species that flower before the seasonal peak in temperature and delayed in species that flower after the peak temperature (Sherry et al. 2007). Because development is more likely to be limited by temperature early in the growing season when ambient temperatures are relatively low, whereas temperature increase in the latter part of the season may exceed the optimal range, differential effects of temperature increase for early- versus late-flowering species are expected. The changes in phenology, although, are a function of temperature change, it is important to remember that changes in a number of other environmental factors, including atmospheric CO_2, nitrogen deposition and precipitation, correlate with the rise in temperature and also affect phenology (Cleland et al. 2006).

In Europe greenhouses are essentially for heating. While in the summer, a well-placed

Table 19.3 Plants categorized by their base temperatures (Runkle 2006)

Plants with low base temperature (<4°C)	Plants with moderate base temperature (4.4–7.2°C)	Plants with high base temperature (8 or > 8°C)
Ageratum	Calibrachoa	African violet
Alyssum	Coreopsis	Angelonia
Campanula	Dahlia	Begonia (fibrous)
Cineraria	Impatience	Blue Salvia
Diascia	Salvia	Caladium
Easter lily		Celosia
Gaillardia		Gazania
Leucanthemum		Hibiscus
Marigold (French)		New Guinea impatiens
Nemesia		Pepper
Petunia		Phalaenopsis orchid
Rudbeckia		Poinsettia
Scabiosa		Rose
Snapdragon		Vinca
Thanksgiving cactus		
Viola		

greenhouse will gain most of its warmth directly from the sun, in the winter, the focus is on artificial ways of heating the greenhouse and insulating it from cold prevailing winds. A wide range of heating systems are being utilized, ranging from central heating with water heated by gas, oil, wood or coal burners, circulating through pipes, to self-contained portable radiators, paraffin burners, fan heaters and bottled gas units. Heating constitutes the major energy requirement for the high-technology greenhouses of north and central Europe. In these greenhouses and for heat-demanding crops, such as rose, tomato or cucumber (Baille 1999), estimated annual greenhouse heating requirements are about 3,000 MJ m^{-2} $year^{-1}$ in northern European countries, 1,600 MJ m^{-2} $year^{-1}$ in Southern France and 1,200 MJ m^{-2} $year^{-1}$ in Israel.

19.3 Likely Impact of Climate Change on Floriculture of India

From the above sections, it is clear that increased CO_2 is affecting most of commercial flower crops positively. Few ornamental crops responded positively to even increase in temperature under controlled conditions. Some crops like tuberose, gladiolus, marigold and aster are not so sensitive to high temperature. But so far, studies on CO_2 enrichment and high temperature effects under field condition on gladiolus, marigold, annual chrysanthemum, tuberose, aster, etc. are lacking.

19.3.1 Protected Cultivation

Most of commercial flower crops are grown under protected condition; therefore, change in climate may not affect global floriculture. But in India, commercial floriculture practised under protected conditions is limited (about 5–10% of the total area) and restricted to the few regions of country. Flower crops particularly grown under open field conditions may be affected due to change in climatic conditions leading to poor flowering, improper floral development and colour besides reduction in flower size and short blooming period. It was expected that the floriculture under protected conditions increases significantly due to increasingly growing demand, governmental support in terms of finance and infrastructure technological advances from the public sector R&D.

19.3.2 Hardy Crops

The impact of climate change on flowering plants and crops will be more pronounced. Melting of ice cap in the Himalayan regions will reduce chilling period required for the flowering of many of the ornamental plants like Rhododendron, Orchid, Tulipa, Alstromeria, Magnolia, Saussurea, Impatiens and Narcissus. Some of them will fail to bloom or flower with less abundance while others will be threatened. Indigenous species in the natural habitat will be under threat for not getting favourable agro-climatic conditions for their proliferation. Western Ghats and surrounding regions may be deprived of normal precipitation due to abnormal monsoon. Plant species requiring high humidity and water may find it difficult for survival. Plains of India will also have similar kind of problems and will be affected either by drought or excessive rains, floods and seasonal variations.

On the other hand, in tropical country like India, all the means and ways are employed to reduce the temperature inside the greenhouse. In both the cases, outside climate is changed to suit to the needs of the crop. Change in microclimate is the chief objective of protected agriculture. In fact, greenhouse heating is a common practice in Europe during severe winters when the atmosphere temperature goes below 0°C (for few days to weeks). Intensive cropping of flowers and vegetables also helps in vertical farming.

In Western countries, more than 80% flower production is in protected structures. Whereas in India at present, it is about 5% and expected to increase significantly owing to the support from government of India through various agencies and advances in technology especially from public sector R&D. The desperate need for enhancing farm income per unit area as there is saturation in the production under open field cultivation is encouraging the protected cultivation.

Under protected cultivation as the climate is already modified, the global climate change would not be affecting the growth and flowering rather it may have a little effect on the energy charges and thereby the cost of production.

19.4 Future Strategies

To mitigate the challenge of changing climate, we need to be proactive to understand and visualize climatic variation in future and work in collective and collaborative manner with multi-institutional approach. Floriculturists will have to play a significant role in the climate change scenario, and proper strategies have to be envisaged for saving floriculture from future turmoil. The most effective way to address climate change is to create awareness among grower to adopt a sustainable development pathway, besides using renewable energy, forest and water conservation, reforestation, etc. Awareness and educational programmes for the growers, modification of present cultural practices and greater use of greenhouse technology are some of the solutions to minimize the effect of climate change. Hi-tech horticulture is to be adopted in an intensive way. It is necessary that selection of plant species/cultivars is to be considered keeping in view the effects of climate change. The performance in different seasons may not be satisfactory due to shorter and warmer winter. Judicious water utilization in the form of drip, mist and sprinkler will be a key factor to deal with the drought conditions. Development of new cultivars of floricultural crops tolerant to high temperature, resistant to pests and diseases, short duration and producing good yield under stress conditions will be the main strategies to meet this challenge.

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20 Strategies for Soil Carbon Sequestration Through Horticultural Crops

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Abstract

Horticulture in our country has brought about a significant change in the outlook of the growers. The need for great utilization of available wastelands against the background of dwindling water and energy resources has focused attention to dry land, to arid and semiarid tracts, and to horticultural crops which have lesser demands for water and other inputs besides being 3–4 times more remunerative than field crops. Horticulture crops have greater potential for carbon sequestration than field crops and agroforestry systems. This chapter deals with issues related to strategies to enhance carbon sequestration under horticultural production systems in India.

20.1 Introduction

India, having a diverse soil and climate and comprising several agroecological regions, provides ample opportunity to grow a variety of horticulture crops. These crops form a significant part of total agricultural produce in the country comprising of fruits and nuts, vegetables, root and tuber crops, flowers, ornamental plants, medicinal and aromatic plants, spices, condiments, plantation crops, and mushrooms. A total of 12.083 million ha of area (6.101 m ha of fruits, 3.217 m ha of plantation crops, 2.629 m ha of spices, 0.136 m ha of nuts) is under perennial horticultural crops and yields an annual production of 214 million t. Though these crops occupy hardly 7% of the cropped area, they contribute over 18% to the gross agricultural output in the country.

The recent emphasis on horticulture in our country consequent to the recognition of the need for attaining nutrition security and for more profitable land use has brought about a significant change in the outlook of the growers. The need for great utilization of available wastelands against the background of dwindling water and energy resources has focused attention to dry land, to arid and semiarid tracts, and to horticultural crops which have lesser demands for water

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and other inputs besides being 3–4 times more remunerative than field crops. It is estimated that India has 240 million ac of cultivable wasteland, which can be brought under orchard crops without curtailing the area under food crops. The country has abundant sunshine throughout year, surplus labor, and widely varied agroclimatic conditions, which offer high potential for successful and profitable commercial horticulture.

20.2 Soil Organic Matter

There is fairly a wide range of definitions for soil organic matter based on studies on characterization, fractionation, and dynamics of carbon in soil. Basically it is accepted that the term soil organic matter designates a highly heterogeneous pool that includes numerous carbonaceous compounds; these range from easily mineralizable sugars to complex and recalcitrant products of microbial transformations whose residence times vary from a few minutes to hundreds of years (Buyanovsky et al. 1994).

20.2.1 Time Intervals of Organic Carbon Equilibrium

Under normal situations, it takes 15–100 years for organic carbon to attain equilibrium in soil (Brown and Lugo 1990; Dick et al. 1998). Even longer period is also reported. For example, in Broadbalk wheat experiment with an annual application of 34 t FYM $ha^{-1}year^{-1}$, the soil organic carbon content is still on the increase (Jenkinson 1990). When soil organic carbon is lost from the system due to a change in land use or due to fire or any other reason, the time taken for total soil organic carbon recovery varies very widely depending upon the new crop/management, soil/latitude/altitude/moisture/biological activity in soil, etc. For example, about 2000 years are needed for total soil organic carbon recovery subsequent to forest fires in boreal forests (Liski et al. 1998). Keeping other factors common, the recovery interval is longest in northern latitudes and at higher altitudes. Further, the rate of recovery of soil organic carbon is more rapid in wet and moist life zones. Long-term experiments have shown that even with higher yields, the soil carbon in the top layers reached steady state only little above the equilibrium levels attained in unmanured plots. This demonstrates that the net rate of accumulation of organic matter depends not much on the protective capacity of the soil per se but rather on the extent to which this capacity is already occupied by the organic matter. The terrestrial sink for carbon can become saturated because photosynthesis follows a saturation function with respect to CO_2, and because plants and microbial respiration must catch up as the rate of increase in photosynthesis slows down, this would eventually reduce the possibilities for incremental carbon storage to zero. Thus, there is likely to be an upper limit to the biomass that can be held by perennial crop stand and other stands (Phillips et al. 1998).

20.2.2 Soil Organic Carbon Equilibrium Status in Horticultural Systems

The soil is a very large sink for organic carbon and has a long resident time. The soil-forming factors like climate, vegetation, biological activity, and man's influence control the amount of soil organic matter that corresponds with the equilibrium condition in horticulture ecosystems. Unlike forests, horticulture is characterized by disturbed equilibrium system because as the fruit trees become uneconomical the trees are removed and new planting is done. Therefore, under horticultural ecosystems, the steady state of soil organic carbon frequently gets disturbed, and a new steady state is attained. A schematic diagram of the status of soil organic carbon equilibrium is given in the Fig. 20.1 below.

Every time the orchard is replanted, the organic carbon status falls down due to a rude shock to the established equilibrium. Hence, after each disturbance, a period of constant management is required in order to reach a new steady state. Depending upon the kind and level of

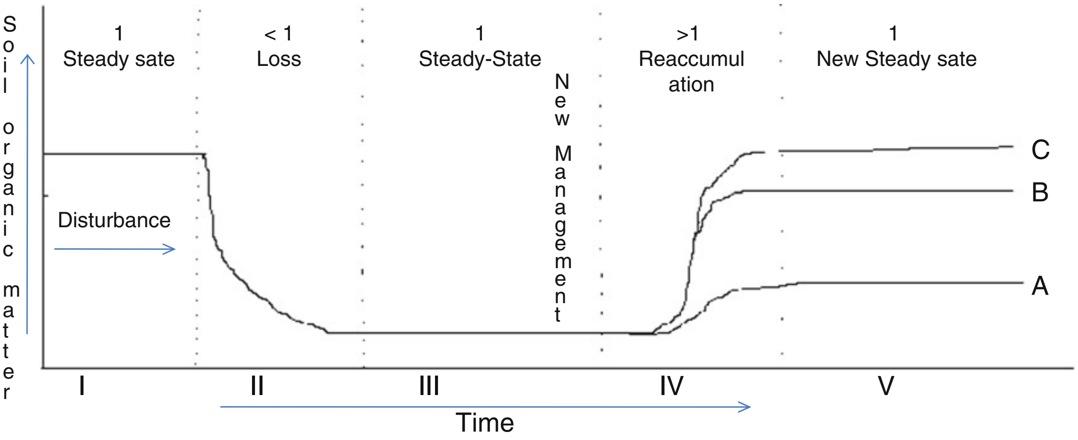

Fig. 20.1 Carbon equilibrium in horticultural systems

management, the steady state attained after new planting may be below or at par or even above the original steady-state level.

20.3 Factors Controlling Soil Organic Matter Dynamics Under Horticulture Systems

20.3.1 Organic Matter Inputs

There are two important biological processes that control soil organic matter dynamics. These are:

(a) Primary production that includes the rate and quality of carbon transfer belowground

(b) Soil microbial activity

The input rates of organic matter and the quality of the carbon in the vegetation are largely dependent on climate parameters like temperature and precipitation; type of vegetation like whether it is a woody tree like mango, litchi, apple, or soft tissue like banana or papaya; landscape like sloppy land and level land; soil type; and orchard management practices like conservation horticulture and intensive orchard management.

Plant residues that fall on the soil like fresh litter are gradually altered through physical fragmentation, soil fauna, microorganisms' interactions, mineralization, and humus formation. Decomposition process and turnover rates are largely influenced by climate, type and quality of organic residues, chemical and physicochemical association of organic matter with the soil mineral components, and the location of the organic matter within the soil (Jastrow and Miller 1997). Changes in soil organic matter quality are more important for carbon sequestration than changes in the quantity of organic matter. Mean annual mineralization is about 4–5% in humid tropics compared to 2% in the temperate climate. Within the given region, the rate is more rapid under intensive cultivation than under conservation tillage or zero tillage. Biomass production is limited by nutrient supply in the soil and is highest in humid tropics.

20.3.2 Biological Mitigation

Figure 20.2 shows the main processes that influence soil organic matter sequestration. There are three principal processes of soil carbon sequestration. These are humification, aggregation, and sedimentation.

Countering these are the processes that decrease the sequestered soil organic carbon. These include erosion, decomposition, volatilization, and leaching.

Several soil and climatic parameters control soil organic matter behavior in soil. These are

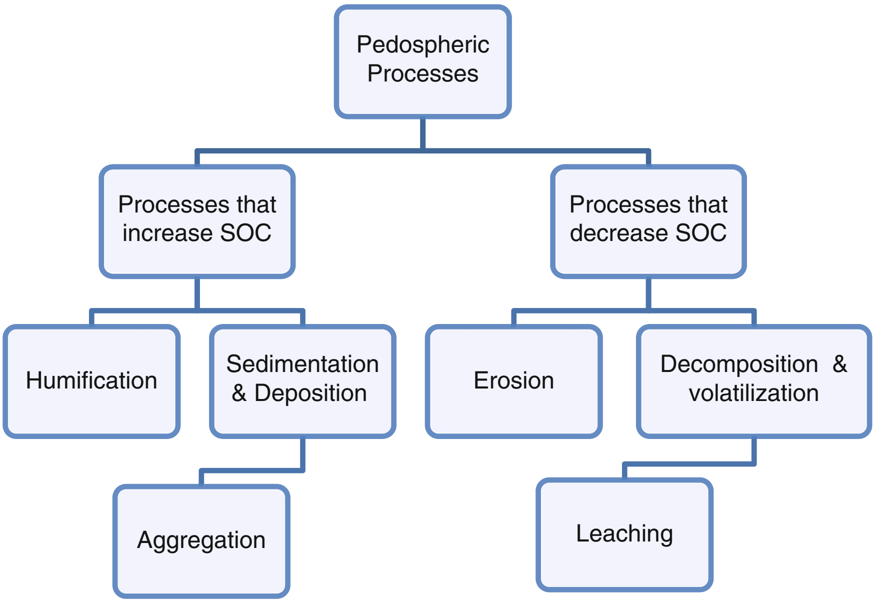

Fig. 20.2 Processes that influence soil organic matter sequestration

soil moisture status, soil temperature, drainage (oxygen supply), soil acidity, soil nutrient supply, soil clay content, and mineralogy.

As a general rule with increasing precipitation, the soil organic carbon density increases, and at a given level of precipitation, the SOC decreases with increasing temperature. Changes in SOC have been shown to correlate with changes in the structural forms and stability of soils, and the magnitude of changes in structural characteristics of the soil is often strongly dependent on soil structure (Kay 1998). The mechanisms responsible for stabilization of SOC include physical protection, biochemical recalcitrance, and chemical stabilization.

The nature of soil organo-mineral association, that is, the clay-humus complexation, and the location or distribution within soil aggregates determine the extent to which the soil organic matter is protected against carbon mineralization through physical protection and chemical stabilization resulting in organic pools with varying input and turnover rates. Carbon mineralization in surface layers is related to biological activity like earthworms, vegetation type, and external input in the form of manure amendments. The main processes leading to carbon emission in horticultural systems are given below (Fig. 20.3).

20.4 Stability of Carbon in Soil

Two fundamental management-related axioms of soil organic matter dynamics are that (a) soil organic matter increases with increasing carbon inputs and (b) decreases with physical disturbance of the soil although the quantitative relationships are not well characterized and vary depending upon the situation. Decrease in soil organic carbon can be abated by improved practices including decreasing bare fallow, reducing tillage intensity, and increasing use of perennial vegetation. No-till not only reduces soil disturbances and thus decomposition but also enables more water conservation which allows for more intensive crop rotations and hence greater carbon inputs.

Soil aggregate stability is an index of soil organic matter stability. Freshly decomposed organic matter (young organic matter) is largely responsible for macroaggregate stability (Puget

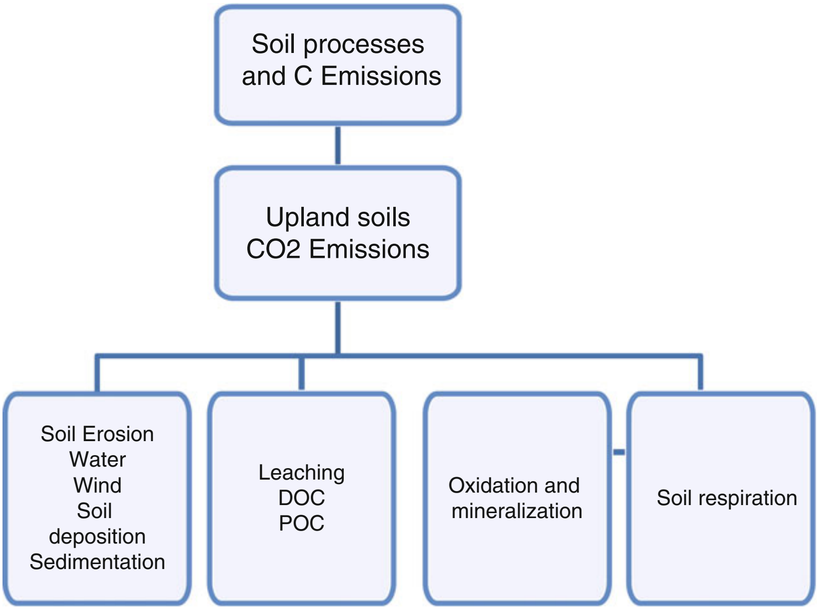

Fig. 20.3 Main processes leading to carbon emission in horticultural systems

et al. 1995). Organic matter associated with macroaggregates has wider C:N ratio and those associated with microaggregates have narrow C:N ratio. Hence, soil organic matter associated with macroaggregates is less stable than those associated with microaggregates. The active fraction of soil carbon plays an important role in determining the aggregate stability and infiltration of water. Protection of soil organic carbon is greatly influenced by the texture of the soil. Coarse-textured soils only contain significant concentrations of physically protected organic matter within aggregates that are mainly enriched in plant residues; as a result, effects of land-use change on soil organic carbon are generally more apparent on coarse-textured soils than on clayey soils. The decomposition rate of soil organic carbon in the surface layers is higher in light soils than heavy soils, indicating the role of texture on retaining the soil organic carbon. Finer soils like silt and clay fractions contain the most refractory carbon (Feigl et al. 1995). Soil carbon gets attached to soil clays by a variety of physicochemical bonding. These bonding protect soil carbon from microbial degradation. Further, these bonds are very stable and protect the organic matter from decomposition induced by cultivation and other means.

20.4.1 What Influences Soil Carbon Loss

Figure 20.3 shows the factors influencing soil carbon mineralization. Soil intrinsic properties or fixed properties like texture and mineralogy remain unaltered and do not change with change in management in the short period. Factors like substrate quality, moisture, and temperature are directly affected by the climate change. Nutrient availability will be affected by plant removal, external addition, and mineralization of soil organic carbon. The fixed factors will determine the importance of the effects of the more variable factors on carbon mineralization. If fixed properties are the limiting factors for carbon mineralization, then climate change will hardly affect carbon mineralization.

Table 20.1 Estimated ranges in the amounts and turnover time of various types of organic matter stored in horticultural soils (Jastrow and Miller 1997)

Type of soil organic matter	Proportion of total organic matter %	Turnover time Year	Carbon pool
Microbial biomass	2–5	0.1–0.4	Labile
Litter	–	1–3	Rapid
Particulate organic matter	18–40	5–20	Moderate
Light fraction	10–30	1–15	Moderate
Inter-microaggregate[a]	20–35	5–50	Moderate to slow
Intra-microaggregate[b]			
Physically sequestered	20–40	50–1,000	Passive
Chemically sequestered	20–40	1,000–3,000	Passive

[a] Within macroaggregates but external to microaggregates including particulate, light fraction, and microbial C
[b] Within microaggregates including sequestered light fraction and microbially derived C

20.5 Soil Carbon Pools and Carbon Sequestration in Perennial Systems

With respect to carbon sequestration, it is most desirable to fix atmosphere carbon in those pools having long turnover time. In terms of the resident time, the soil organic pools must be divided into several homogenous compartments. Based on carbon dynamics under perennial systems, soil carbon can be grouped into four main groups (Eswaran et al. 1995):

1. Active or labile pool: Its formation and quality in perennial systems are influenced by climate change and are dictated by the type of management that results in plant residue inputs.
2. Slowly oxidized pool: This pool is mainly associated with the soil macroaggregates. This pool of soil organic carbon is influenced by soil physical properties like mineralogy and aggregates and horticultural practices.
3. Very slowly oxidized pool: This pool is mainly associated with the soil microaggregates where in the main controlling factor is the water stability of the aggregates. Horticultural practices have only little effect on its formation.
4. Recalcitrant or passive pool: This pool is mainly controlled by the soil mineralogy. Horticultural practices have no effect on its formation. The resident time of different types of organic matter, their proportion in total organic matter, and the resident time of these pools of soil organic carbon are presented in the Table 20.1.

20.6 Potential of Horticulture for Carbon Mitigation Projects for Carbon Credits

Biological mitigation can occur through these three strategies:

1. Conservation of existing carbon pools
2. Sequestration by increasing the size of existing pools
3. Substitution of sustainably produced biological products, such as using wood of fruit trees instead of energy-intensive construction materials or using biomass to replace energy production from fossil fuels

Options (1) and (2) result in higher carbon stocks but can lead to higher carbon emissions in the future (e.g., through fires or land clearing for agriculture), whereas (3) can continue indefinitely (IPCC 2001). Opportunities for biological mitigation in tropical countries cannot be considered in isolation of broader policies in agriculture, horticulture, forestry, and other sectors. Barriers to reaching the potential level of mitigation include:

1. Lack of funding and human and institutional capacity to monitor and verify mitigation efforts and outcomes.

Table 20.2 Potential for carbon sequestration in tropical countries (in Gt C by 2050)

	Production system		
	Horticulture and plantations	Forest	
Source		Agroforestry	Regrowth
Trexler and Haugen (1994)	2.0–5.0	0.7–1.6	9.0–23.0
Brown et al. (1996)	16.4	6.3	11.5–28.7

2. Food supply requirements.
3. People living off the natural forests.
4. Importance to perennial horticultural crops has not received the due attention it deserved.
5. Existing incentives for wasteland utilization are not encouraging.
6. Population pressure.

Horticulture and agroforestry have wide potential for sequestering carbon and can offset greenhouse gas emissions. However, horticulture and plantations have a clear edge over agroforestry for carbon sequestration potentials. Bloomfield and Pearson (2000) presented a review of estimates of the potential of land-use change and horticulture (LUCH) and land-use change and agroforestry (LUCF) activities to offset greenhouse gas emissions. Some of their figures are presented in Table 20.2. Brown et al. (1996) estimate that, by 2050, horticulture and plantations in tropical countries have the potential to capture as much as 16.4 Gt C, whereas agroforestry has the potential to capture 6.3 Gt C. The estimates of Trexler and Haugen (1994) are much lower than this, especially for agroforestry, indicating that there is a large degree of uncertainty regarding estimates of potential carbon sequestration at a global scale.

Perennial horticulture including fruit crops, plantations, spices, and nuts and that of aforestation and reforestation of degraded forests and wastelands offer attractive opportunities. But the mitigative capacity may be weak, and enough land and water may not be available. Also, much of the land in the tropics is managed by semi-subsistence farmers and shifting cultivators, so their willingness to participate in biological mitigation projects may be an important factor (de Jong et al. 2000). The CDM requires sustainable development goals to be met as well as sequestration goals. This means that smallholders are likely to be an important group. However, projects must be in line with the sustainable development goals of the host country, which does not necessarily mean large plantations/orchards. Employment benefits to local people may meet the host country's sustainable development objectives.

20.6.1 Conceptual Framework of Carbon Sequestration in Perennial Horticulture and Plantations

The conceptual framework of carbon sequestration in perennial systems is presented in Fig. 20.4. On one side, we have the global warming problem that creates a demand for certified emission reductions (CERs). On the other side, we have tropical countries which tend to have problems with deforestation, land degradation, and poverty.

The demand for CERs will be met mostly by the energy sector, through clean technologies. However, land-use change and horticulture (LUCH) projects may also have an important role to play. This is partly because of cost differentials with other forms of mitigation and partly because adopting new technologies for efficient use of fossil fuels may require scrapping existing infrastructure and may require considerable capital investment. Mitigation projects in tropical countries can be roughly split into projects involving smallholders and commercial and industrial plantations. Smallholder projects consist of activities undertaken by farmers who manage small land areas and whose production system may be a mix of subsistence and marketable crops. Commercial and industrial plantations generally consist of monoculture of commercial plantations, fruit trees for pulp or fruit production, and timber.

The three sources of supply of CERs will exhibit different transformation (production)

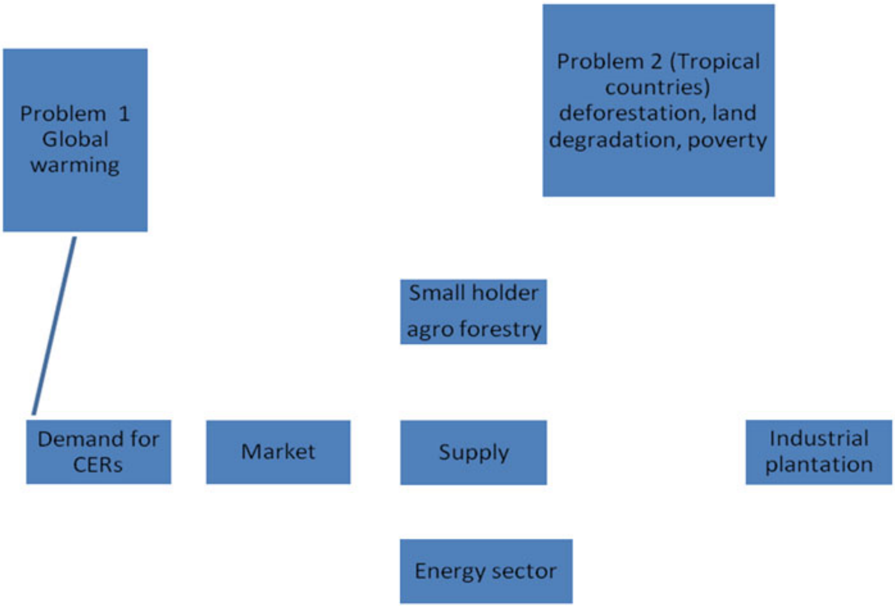

Fig. 20.4 Conceptual framework

costs, expressed as costs per unit of emission reductions. In order to participate in the CER market, suppliers will also incur transaction costs. These include the costs of monitoring and certifying carbon sequestration rates and any other costs required to give investors confidence that the goods they are purchasing actually exist. Additional transaction costs may occur at the market level, some borne by sellers and some by buyers. The sellers of CERs may not be the same as the suppliers. Sellers may be intermediaries who finance project design and implementation either to earn a profit or to contribute to development objectives. Table 20.3 presents a list of possible market participants.

Table 20.3 Potential participants in the market for certified emission reductions (Baumert et al. 2000)

Investor	Objective
Annex 1 government	Meet emission reduction commitment
Non-Annex 1 government	Promote sustainable development
Energy company	Offset emissions
Institutional investors	Portfolio diversification, socially responsible investment
NGOs	Promote environmental and development benefits
Brokers	Profit

20.7 Horticulture for Carbon Sequestration

20.7.1 Relationship Between Orchard and Plantation Aging and Carbon Sequestration

To sequester one ton of carbon from the atmosphere, it is necessary to produce about 2.2 t of wood (Chaturvedi 1994). Carbon sequestration by trees is much faster in the tropical belt due to favorable climatic conditions. In perennial horticulture and plantations, the growth rates and hence carbon sequestration potential diminish as trees approach maturity. Orchards and plantations accumulate carbon in young and middle age, but the rates approach zero as the trees mature. The reasons for this decline in the aboveground net primary production in mature orchards and plantations are:

- An altered balance between photosynthetic and respiring tissues
- Decreasing soil nutrient availability
- Increasing stomatal limitations leading to reduced photosynthetic rates

Changes in the belowground biomass during orchard stand development and with aging of the orchards are very poorly understood. Hence, it is very difficult to speculate how this important flux may change during development of the orchards, plantations, and gardens. The long residence time of particulate organic matter from high-latitude forest soils, however, provides indirect evidence that if fluxes of carbon from vegetation to the soil increase, as a result of global change, these soils have the capacity to act as a carbon sink on decadal time scale.

20.7.2 Why Horticulture for Carbon Sequestration?

Perennial fruit trees, gardens, plantations, etc. contain 25–100 times more biomass carbon than agricultural lands. Hence, vacant and wastelands should preferably be allocated to perennial horticultural systems than for agroforestry or agricultural crops. There are three reasons to consider horticulture as a prime area to offset greenhouse gas emission and to sequester carbon:

- Trees are deep-rooted and have large reserves and are less susceptible than annual crops to interannual variability or short-lived extreme events like droughts or floods. Thus, trees offer diversification options that can reduce production risks for smallholder farmers.
- Trees are a perennial resource that can be exploited to provide increased income during difficult periods, thereby reducing income risks associated with climate-related shocks for smallholder farming families.
- The quantity of carbon sequestered under horticulture and plantations is higher than agroforestry systems.

Tree-based systems are a convenient way of sequestering carbon from the atmosphere to reduce net emissions. Through the process of photosynthesis, trees absorb carbon dioxide (CO_2) which remains fixed in wood and other organic matter in orchards and gardens for long time periods. This is important for tropical countries like India which has large areas as deforested degraded land that can be used for perennial horticulture.

The properties which are likely to make a woody perennial suitable for soil fertility maintenance or improvement are:

1. A high rate of production of leafy biomass
2. A dense network of fine roots, with a capacity for abundant mycorrhizal association
3. The existence of deep roots
4. A high rate of nitrogen fixation
5. A high and balanced nutrient content in the foliage; litter of high quality (high in nitrogen, low in lignin and polyphenols)
6. An appreciable nutrient content in the root system
7. Either rapid litter decay, where nutrient release is desired, or a moderate rate of litter decay, where maintenance of a soil cover is required
8. Absence of toxic substances in the litter or root residues
9. For soil reclamation, a capacity to grow on poor soils
10. Absence of severe competitive effects with crops, particularly for water
11. Low invasiveness
12. Productive functions, or service functions other than soil improvement

Not all of these properties are compatible: for example, litter of high quality is not likely to have a moderate rate of decay. The last property, the existence of productive functions, is not directly concerned with soils but is of the highest importance if the tree is to be effective in fertility maintenance. A species needs to be acceptable and desirable in agroforestry systems from other points of view, especially production. A tree might have all the above desirable properties, but if it is not planted and cared for, it will not be effective in improving soil fertility.

20.8 Carbon Sequestrations in Peri-urban and Urban Horticultural Land

20.8.1 Turfgrass

Although not an agricultural enterprise in the usual sense, turfgrass represents an important feature in urban horticulture including domestic lawns and golf courts. Many land areas previously used for agriculture have now become part of the urban landscape, including lands that have been converted to C-sequestering turfgrasses. Rates of SOC sequestration under turf have a fairly broad range, from 0.32 to ~1 t C ha^{-1} $year^{-1}$ (290–890 lb ac^{-1} $year^{-1}$) (Qian et al. 2010). Using the lowest rate of sequestration of about 0.32 t C ha^{-1} $year^{-1}$ (290 lb C ac^{-1} $year^{-1}$) applied to the 16 million ha (40 million ac) of turfgrass as reported by Milesi et al. (2005), critical needs in turfgrass include:

1. Knowledge to incorporate the combined effects of urbanized land area expansion with agricultural land area losses into national estimates of soil C sequestration
2. Improved quantification of rates and areas for C sequestration under various urban land uses
3. Obtaining a better understanding of the role that growing turfgrass may have on emissions of other GHGs such as N_2O and CH_4 (Table 20.4)

Table 20.4 Critical research needs for developing and implementing horticultural carbon sequestration practices

Topic	Critical needs
Annual horticulture systems (vegetables/aromatic and medicinal plants)	Clarify tillage and environment interactions on soil C
	Quantify above- and below ground C contributions
	Evaluate C practices for total GHG emissions
	Conversion of biowastes into biochars
Perennial horticulture systems (fruit trees, palms, spices, nuts)	Evaluate feasible practices for storing soil C
	Quantify C sequestration in promising systems
	Evaluate benefits beyond C sequestration
Turfgrass	Incorporate effects of urbanization in national C estimates
	Quantify C sequestration for various urban uses
	Evaluate the role of turfgrass systems on the emission of non-CO_2 trace gases

20.8.2 Measuring Carbon Stocks in Horticultural Systems

The recommended approach to measuring carbon sequestration in horticultural gardens is to use permanent sampling plots to monitor both the baseline and the orchards. Well-established statistical techniques can be used to determine the sampling design and intensity required to achieve a given level of precision. For large areas, random subsamples of permanent sampling plots can be monitored each year. Mega orchard areas may also benefit from imaging techniques and remote sensing based either on satellites or low-flying airplanes.

Accounting for carbon sequestration in horticultural projects involves measuring four pools:

- Aboveground living biomass
- Belowground living biomass
- Necromass
- Soils

Not all of these are likely to be acceptable as sources of sequestration in a carbon market, and not all pools need to be measured at the same level of precision or at the same frequency during the life of the orchards. In the initial inventory, the relevant carbon pools must be measured to establish the baseline, but in subsequent monitoring, only selected pools need to be measured, depending on the type of project (Brown 2001). The level of precision to which each pool can be measured at reasonable cost was estimated by Hamburg (2000). The measurement of each pool is briefly explained in Table 20.5.

20.8.2.1 Aboveground Living Biomass

There are standard, well-accepted methods of measuring aboveground biomass carbon in forests. The same is extended to horticultural crops. The simplest procedure consists of measuring a

Table 20.5 Level of accuracy and ease of implementation from measuring different carbon pools in a perennial ecosystem (Hamburg 2000)

Pool	CV	Ease of implementation
Aboveground biomass	5–10%	Simple
Belowground biomass	10–20%	Simple, but requires high initial investment
Soil, organic layer	10–20%	Moderate
Soil, mineral layer	Highly variable	Difficult
Necromass	40%	Difficult

sample of trees and using allometric equations to estimate biomass. Allometric equations relate tree biomass (*B*) to quantities (*Vi*) that can be measured by nondestructive means. Allometric equations have the general form:

$$B = f\left(V_1, V_2, \ldots, V_n\right) \tag{20.1}$$

The independent variables (*Vi*) may include diameter at breast height (*D*), height (*H*), and wood density (ρ). Experience with generic equations has shown that *D* explains more than 95% of the variation in tree biomass (Brown 2001). Brown (1997) has published allometric equations for tropical environments and presents wood density values for a large number of species. The assumption that 50% of aboveground living biomass is carbon is well accepted (Hamburg 2000; Brown 2001), so it is straightforward to convert measured biomass to carbon units. Allometric methods are very robust among species and genera and can predict biomass of closed canopy forest to within ±10% uncertainty. In some special cases, it may be necessary to use destructive techniques to estimate allometric equations for a project, but in general, values available in the literature can provide acceptable levels of precision. Hence, the main expense would be field measurement of trees.

20.8.2.2 Belowground Living Biomass

Belowground living biomass consists mostly of roots. This is an important pool that can represent up to 40% of total biomass (Cairns et al. 1997). It can be very expensive to sample directly and requires destructive techniques (Brown 2001). This pool can be estimated with some accuracy, but at lower precision than aboveground biomass. The simplest approach to estimating belowground biomass is to apply a constant root/shoot ratio (R/S ratio). Although the R/S ratio varies with site characteristics and stand age, a range of R/S ratios can be obtained from the scientific literature (Hamburg 2000). To avoid measuring roots, a conservative approach recommended by Mac Dicken (1997) is to estimate root biomass at no less than 10% or 15% of aboveground biomass. Hamburg (2000) recommends a default R/S ratio for regrowing forests of 0.15 in temperate ecosystems and 0.1 in tropical ecosystems. Although ratios as high as 0.4 have been measured in temperate forests, the author recommends erring on the side of caution to avoid the possibility of crediting nonexistent carbon.

20.8.2.3 Soil Carbon

Soil carbon can also be expensive to measure directly, particularly because of the strong influence that soil characteristics have on carbon dynamics. Hamburg (2000) argues that by using a few generalized principles, it should be feasible to measure soil carbon to an acceptable level of accuracy for biological mitigation projects. He recommends that the soil carbon be measured to at least one meter of depth and that measurements of soil carbon and bulk density be taken from the same sample. Fortunately, for projects that are known to have nondecreasing effects on soil carbon, it may not be necessary to measure soil carbon after the baseline is established. Rates of soil oxidation (a process that releases CO_2) under different land uses are available in the literature (Brown 2001). As a general rule, reforestation projects in agricultural or degraded land would tend to increase soil carbon. If the marginal cost of measuring this carbon pool is greater than the marginal benefit of the carbon credits obtained, the project developer would be better off not measuring this pool. The Alternatives to Slash and Burn (ASB) group have argued that most of the sequestration potential in the humid tropics is aboveground rather than in the soil. In tree-based systems planted to replace degraded pastures, they found that the time-averaged carbon stock increased by 50 t/ha in 20 years, whereas the carbon stock in soil increased by 5-15 t C/ha (Tomich et al. 1998; Palm et al. 1999). Modeling can complement monitoring techniques (Brown 2001). This can be particularly useful to forecast slow changes in soil carbon pools. An example of this technique is presented by Wise and Cacho (2002).

20.8.2.4 Necromass

The necromass pool includes the carbon contained in dead trees, leaves, branches, and other vegetation. Annual leaf litter inputs do not need to be accounted as part of the necromass pool, since this input is balanced by decomposition losses within the soil and the net effect is included in the measurement of the soil pool (Hamburg 2000). The amount of necromass varies considerably with forest type and disturbance history, and estimating this component accurately can be very time consuming and subject to high uncertainty. Fortunately, this component can be ignored (Hamburg 2000) if we are confident that it will not decrease as a result of the project. Brown (2001) states that dead wood, both lying and standing, is an important carbon pool in forests and should be measured. Methods for this component have been tested and require no more effort than measuring living biomass.

20.9 Management Options for Increasing Carbon Sequestration in Horticulture Systems

Management options for orchards are location specific, region specific, soil specific, and societal and cultural specific. Enhancement in the growth and productivity of horticultural plants, both perennial and annuals, can be achieved mainly through soil health management. Carbon sequestration is only a consequence of the enhanced growth and productivity of the crops. Hence, attention should be given for soil management options to enhance carbon sequestration. Basically there can be three main management options for reducing the GHG and for managing soil organic carbon:

- Maintaining the existing levels of soil organic carbon
- Restoring depleted levels of soil organic carbon
- Enlarging soil organic pools above their historic carrying capacity keeping in mind that these increases may be of finite magnitude and duration

Soils most degraded or depleted in organic matter may have the highest potential for increased carbon sequestration under appropriate management. There are many management options for enhanced carbon sequestration in the soil. These include one or a combination of the following practices:

1. Tillage methods and residue management (conservation tillage, cover crops, mulching, etc.)
2. Soil fertility and nutrient management (all management options to enhancing nutrient use efficiency and nutrient cycling)
3. Water management (life saving/supplemental irrigations, surface and subsurface drainage, water harvesting, etc.)
4. Erosion control (contour bunding, terracing, trenching, soil surface amendments, and mulching)
5. Selection of crops, intercrops, cover crops, etc.

The management strategies mainly focused on horticultural systems is presented in the Table 20.6.

20.9.1 Typical Examples of Carbon Sequestration from Horticultural Systems

Although measuring carbon storage is difficult due to the multiple variables involved (even plots in the same region with similar tree species

Table 20.6 Management strategies for better carbon sequestration in horticultural systems

Systems	Management
Land use	Bringing degraded and culturable wasteland under perennial horticulture crops like mango, ber, anona, amla, litchi, pomegranate, apple, and peach, depending upon the location of these lands and climatic requirement of the crops. Superimposing with cover crops, erosion control measures, and fertilization provide lifesaving irrigation through water harvesting practices and control of pests and diseases
Farming systems	As far as possible, avoid monoculture. A mixed orcharding involves crops like pomegranate, anona, ber and amla or mango, litchi, guava or apple, and pear along with cover crops. These will enhance biodiversity and minimize expenditure on nutrients, pest and disease control, etc. in addition to engaging farmers in multiple activities and providing insurance against failure of one of the crops in the systems
Tillage	To enhance carbon sequestration, minimize expenditure on cultivation, protect soil health and conserving organic carbon and water, and follow conservation tillage practices, mulching, etc
Fertility maintenance	Use fertilizers and organic manures judiciously, follow all practices that enhance nutrient use efficiency, nutrient cycling through cover crops, use of legumes, enhancing earthworm activity, use of VAM fungi and biofertilizers, etc
Biochar preparation and incorporation	Convert all pruned material, litters, and other kinds of crop residues available under horticultural systems into biochar and incorporate it in the soil to enhance carbon sequestration and to improve soil health
Pest management	Use pesticides in a highly selective manner and protect natural enemies. As far as possible, use botanicals. Follow IPM practices

composition can vary in their storage capacity depending on microclimate, soil types, etc.), recent research has revealed some encouraging facts. A few examples are:

- In the tropics, potential carbon sequestration rates for smallholder, sustainable agroforestry systems range from 1.5 to 3.5 Mg (tons) per hectare per year or 2.1 billion Mg annually worldwide.
- It has been estimated that each hectare of sustainable agroforestry in the tropics could potentially offset 5–20 ha of deforestation.
- Models have estimated that a 5-year-old coffee farm shaded with two common tree species (*Erythrina poeppigiana* and *Cordia alliodora*) could sequester 5.3 Mg per hectare.
- Soil carbon stocks in shade coffee were 60% of that expected in primary forest in Sumatra versus 45% for sun coffee.
- In El Salvador, carbon sequestration values for various types of shade coffee management were estimated (in tons per ha per year): 174 for rustic shade to 77 for shade monoculture.
- A study of carbon stocks in Costa Rican coffee farms calculated aerial (aboveground) carbon stocks ranging from 11 Mg per ha for simple shade (one heavily pruned shade species) to nearly 32 for diverse shade.

20.9.2 Annual Crop Systems in Horticulture Sectors and Carbon Sequestration

(7.9 M.ha of vegetables and 0.167 M.ha of flowers, 0.43 M.ha of aromatic and medicinal crops)

Specialized field management practices and diverse rotations have discouraged the use of conservation tillage in most vegetable operations, including those under dry land, arid, and irrigated conditions. However, limited research suggests promising uses of cover crops for promoting increased soil C storage in vegetables (Ganeshamurthy 2009; Al-Sheikh et al. 2005).

Recommended management practices to increase SOC in annual crop systems in horticulture sector include increasing cropping frequency and growing high-residue crops.

Alternatively, soil C losses can be minimized by reducing soil tillage, maximizing plant water use efficiency, and application of surface mulches that shade the soil. Incorporation of legumes can be especially effective to allocate a higher percentage of plant biomass carbon to belowground soil carbon sequestration, extend the growing season, better utilize soil water, and reduce tillage compared to annual crops. Improved practices on croplands can increase SOC sequestration rates from 0.1 to 1 t C ha^{-1} year^{-1} (89–890 lb C ac^{-1} year^{-1}), with accumulation rates diminishing as soils approach new equilibria. The vegetable biomass such as plant parts left after the harvest of the economic produces may be converted into biochars and incorporated into the soil so that the carbon may be retained for long time in the soil.

20.10 Critical Research Needs in Horticulture for Enhancing Carbon Sequestration

For further enhancing C sequestration of cropped systems includes:

1. Clarifying the interactions among tillage, climate, and soil type on C sequestration
2. Quantifying above- and belowground plant contributions to SOC
3. Evaluating C sequestration practices for total GHG emissions, since recommended practices like incorporation of legumes or fertilizer additions, which enhance soil C, may enhance the soil release of N_2O
4. Biochar production from horticultural wastes
5. Evaluate potentially feasible horticultural management practices for storing soil C
6. Quantify C sequestration in promising horticultural systems
7. Further evaluate benefits of conservation practices beyond C sequestration
8. Tree pruning to enhance light penetration in orchards to enhance photosynthesis
9. Conversion of tree-pruned biomass into biochars and incorporation into the orchard soils to retain carbon in soil

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Impact of Climate Change on Fruit and Vegetable Quality

21

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Abstract

Nutritional quality of fruits and vegetables depends on genetic and environmental factors. Soil factors, temperature, light and CO_2 are the major factors which determine the quality of horticulture produce. Most of the health-benefiting nutrients including vitamins, minerals and antioxidants are supplied through fruits and vegetables. However, the changed climate has affected the quality of many fruits and vegetables. Elevated CO_2 has improved the vitamin C, sugars, acids and carotenoids in oranges, tomatoes and strawberries. Positive effect of CO_2 was also observed on total antioxidant capacity, phenols and anthocyanins in fruits and oil palm. However, elevated CO_2 may decrease the protein and mineral content of the produce. High-temperature stress is known to decrease vitamin C, starch, sugars and many antioxidants especially anthocyanins and volatile flavour compounds in fruits. Deficit irrigation increases sugars, anthocyanins and even volatiles in strawberries and tomatoes. However, severe stress decreases the quality of fruits and vegetables. A higher temperature coupled with water stress is going to definitely reduce the fruit and vegetable quality in terms of vitamins, antioxidants and minerals.

21.1 Introduction

The diverse agro-climatic conditions available in India provide ample opportunity to grow a variety of horticultural crops round the year. Most horticultural crops are sensitive to environmental extremes. The periodic high temperature and soil moisture stress conditions are the major causes of low yields. Elevated CO_2, even though increases water use efficiency and yield, can affect the quality of fruits and vegetables since more carbon is fixed in relation to other nutrients. Temperature and water stress can affect the photosynthesis, reproductive growth and mineral uptake, resulting in poor growth of fruits and vegetables. This may lead to lower nutritive value of horticultural produce. In recent years, increasing

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attention has been paid by consumers to the health and nutritional aspects of horticultural products. Fruits and vegetables contain significant levels of biologically active components that impart health benefits beyond basic nutrients. Higher consumption of fruits and vegetables has been associated with a lowered incidence of degenerative diseases including cancer, heart disease, inflammation, arthritis, immune system decline, brain dysfunction and cataracts. Horticultural products are the major source for giving nutritional security. With changes in lifestyles of people due to more urbanisation, lifestyle-related diseases are increasing worldwide. Therefore, it is essential to consume more fruits and vegetables to reduce the risks of many such diseases. In this regard, it is necessary to understand the effect of climate change on the nutritive value of some of the important fruits and vegetables especially with respect to antioxidant properties.

21.2 Elevated CO_2 and Quality of Fruits and Vegetables

As a consequence of anthropogenic activities, the atmospheric carbon dioxide (CO_2) concentration has been increasing, and it could reach 550 μmol mol^{-1} by 2,050 and 730–1,020 μmol mol^{-1} by 2,100. This increase in CO_2 could benefit the crops by reducing the losses in agricultural production caused by increased drought and temperature. Carbon dioxide plays a central role in physiology of plants by acting as carbon fertilisation which increases the growth and yield of plants. Elevated CO_2 has also been reported to enhance the concentrations of a number of bioactive components of fruits and vegetables. Elevated CO_2 effects on physiology and quality of fruits and vegetables have been summarised by Moretti et al. (2010). In their review, increased sugars, ascorbic acid, phenols, flavonoids, anthocyanins, colour, firmness, starch and reduced organic acids, alkaloids were reported for many fruits and vegetables.

21.2.1 Vitamin C, Sugars and Acidity

Antioxidants play a greater role in maintaining human health. Antioxidant compounds of fruits and vegetables have been widely studied and reported to give protection against many degenerative diseases such as cancer, *coronary heart disease*, cataract and arthritis (Shivashankara and Acharya 2010). There is a possibility that the additional carbon fixed by plants during CO_2 enrichment may be invested in protective antioxidant compounds such as ascorbate and phenolics. Quality parameters like organic acids were lower; ascorbic acid and sugars were more in tomato fruits when elevated CO_2 was given at different maturity levels (Islam et al. 1996). Fruit growth and colour were enhanced by the elevated CO_2. Maximum acidity and ascorbic acid were seen at pink stage of ripening and declined slightly at red ripe stage. Even doubling of CO_2 for 1 h in a day over a period of 7 days was also found to increase ascorbic acid by two-folds in bean sprouts (Tajiri 1985). Total sugars and acidity were increased by high CO_2, but the effect was seen only at the middle of the ripening season and not at later stages in grapes (Kurooka et al. 1990; Bindi et al. 2001).

Vitamin C content of sour orange (*Citrus aurantium* L.) was found to increase by 7% when trees were grown at 400–700 μmol mol^{-1} of CO_2 in open-top chambers (Idso et al. 2002) and in strawberry under field conditions (Wang et al. 2003). When compared to the increase in total biomass and yield, the gain in vitamin C was negligible (Leavitt et al. 2003). Elevated CO_2 at 600 μmol mol^{-1} concentration increased fructose and glucose content among the sugars and citric and malic acids among organic acids in strawberry (Sun et al. 2012).

21.2.2 Total Phenols, Anthocyanins and Flavonoids

Effects of elevated CO_2 at 1,000–1,100 μmol mol^{-1} for 8 h/day on grapes at later stages of fruit growth increased the anthocyanin concentration (Kurooka et al. 1990). Increase in total antioxidant capacity, total flavonoids and phenols was reported for oil palm and medicinal herbs when grown at 1,200 μmol mol^{-1} CO_2 as compared to 400 μmol mol^{-1} (Ibrahim and Jaafer 2011, 2012). In addition to ascorbic acid, increased CO_2 concentrations (300–600 μmol mol^{-1} above ambient) have been reported to increase other antioxidants like glutathione (GSH), anthocyanins, total phenolics and flavonoids contents in strawberries (Wang et al. 2003). High-CO_2 grown fruits also showed higher radical scavenging ability. However, when elevated CO_2 (720 μmol mol^{-1}) was combined with increased temperature, total anthocyanins, phenols and flavonoids decreased in strawberry (Sun et al. 2012). Gil et al. (1997) also reported a reduction in total anthocyanin content of internal tissue in strawberry (*Fragaria* × *ananassa* Duch.) at high CO_2. In tomato, increases in antioxidant levels were very less under high CO_2 concentrations (Barbale 1970; Madsen 1971, 1975; Kimball and Mitchell 1981).

21.2.3 Volatile Aroma Compounds

Fruit quality is also assessed by the volatile aroma constituents. Better aroma of consumer preference indirectly represents the good quality of fruits. Aroma profile includes terpenes, esters, alcohols, acids and aldehydes. Wang and Bunce (2004) studied the effect of elevated CO_2 on fruit quality and volatile aroma composition in field-grown strawberries (*Fragaria* × *ananassa* Duch). A significant increase in the content of major esters of strawberry aroma, namely, ethyl hexanoate, ethyl butanoate, methyl hexanoate, methyl butanoate, hexyl acetate, hexyl hexanoate, furaneol, linalool and methyl octanoate was observed under high CO_2 levels. These results raise questions about the beneficial effects of elevated CO_2 on the quality of fruits especially the compounds which contain more nitrogen and involve minerals as cofactors for the synthesis. Nutritive quality of fruits and vegetables depend on the size of the fruits. If the size of the fruits did not change under high CO_2 concentrations, then there may be chances of improvements in the quality.

21.2.4 Mineral Nutrients

In addition to health-promoting bioactive compounds, elevated CO_2 was reported to affect the mineral composition of fruits and vegetables. Decrease in the leaf mineral content (N, P, K, Ca, Mg, S, Cl, Fe, Zn, Mn, Cu and B) was observed for mango under elevated CO_2 (700 μmol mol^{-1}) concentration against control (350 ppm) (Schaffer et al. 1997). Reduced ash content was reported for lettuce grown under high CO_2 (McKeehen et al. 1996). Significant reduction of minerals like N, Ca, Fe, S, Mg and Zn (15–25%) was seen in many species of herbaceous and woody plants under high CO_2 concentrations (Loladze 2002). Initial reduction in protein and mineral content could be overcome in long-term exposures to elevated CO_2 by the enhanced root growth and hence may maintain the quality of fruits and vegetables (Idso and Idso 2001).

21.3 Effect of High Temperature on Quality

21.3.1 Vitamin C, Sugars and Acidity

Temperature plays an important role in determining the phonological stages as well as proper growth and development of plants. All the phonological phases require certain degree days (combination of temperature and number of days) for their completion. High temperatures for longer durations affect several fruit crops of which grapes are the important ones. In grapes, high temperatures generally resulted in delayed fruit maturation and reduction in fruit quality (Kliewer 1971, 1973). High-temperature exposure reduced the starch and vitamin C content significantly in kiwifruits (Richardson et al. 2004). Citrus fruits grown in hot tropical areas have lower levels of vitamin C compared to areas of cool nights (Padayatty et al. 2003; Njoku et al. 2011). Acidity, total soluble solids and dry matter content decreased due to high temperature in tomato (Bikash Khanal 2012). Increased day and night temperatures (30°C/25°C) reduced the soluble sugars, starch, amino acids and proteins in apple (Hsiao-hua Pan et al. 2007).

21.3.2 Phenols, Flavonoids and Anthocyanins

Phenolics determine colour in nearly all wines, and they are major factors in the flavour and aroma of red wines. Phenolics contribute a desirable bitterness and astringency to wine flavour (Webb 1981). High temperatures reduce colour development. Night temperatures are more critical for the anthocyanin content than the day temperatures (Kentaro Mori et al. 2005). Anthocyanin accumulation in the skin of berries grown at high night temperatures (30°C continuous) was reduced as compared to that of berries grown at low night temperatures (30°C/15°C D/N). This was due to inhibition of many anthocyanin biosynthetic genes (Kentaro Mori et al. 2007; Cohen et al. 2012). Wine grapes have many anthocyanin pigments in their skins. Malvidin derivatives are the major pigments. High temperature reduces the synthesis of all the pigments in cv. Cabernet Sauvignon grapes (Kentaro Mori et al. 2007). Exposure of berries for a short duration of elevated temperatures alters the ratio of acylated to non-acylated anthocyanins (Tarara et al. 2008). Solar radiation in combination with high temperature plays an important role in the anthocyanin composition of the berries (Tarara et al. 2008). Low night temperatures may be acting through higher ABA in increasing the anthocyanin content of grapes (Koshita et al. 2007). Increased day and night temperatures (30°C/25°C) reduced the total phenolic content in apple (Hsiao-hua Pan et al. 2007). Optimum condition for better strawberries with high antioxidant content was found to be 33/22°C day/night temperatures. Lower temperatures reduce the antioxidant quality of fruits (Wang and Zheng 2001). A progressive reduction in flavonoid content including anthocyanins was observed when the temperature was increased from 30°C to 45°C (Pan et al. 2004).

Thermal stress induces the accumulation of phenolic compounds like flavonoids and phenylpropanoids. At 35°C, the polyphenol level is doubled compared to 25°C. George et al. (2004) measured a huge variance in polyphenol content (104–400 mg kg^{-1}) of different tomato varieties. This phenomenon could be considered as an acclimation mechanism of the plant to heat stress (Rivero et al. 2001). High temperatures increase the fruit quality if the present growing temperatures are too low to get good-quality fruits as seen in the case of pear fruits in China (Chen et al. 1999).

21.3.3 Lycopene and Carotenoids

Effect of preharvest temperature on the postharvest quality of fruits and vegetables has been extensively reviewed by Woolf and Ferguson (2000). They report that high temperatures reduce the fruit quality as well as mineral content. Lycopene content is also affected by the high day/night temperature treatments (30°/25°C) than control temperature (28°/23°C) in tomato (*Lycopersicon esculentum* Mill., cv. 'Laura') (Fleisher et al. 2006). High solar radiation combined with temperature further reduces the lycopene content and other nutritive value compounds of tomato (Dumas et al. 2003; Helyes et al. 2003; Rosales et al. 2006). The content and synthesis of ß-carotene have been demonstrated to diminish from 40°C upwards (Gautier et al. 2005). Direct solar radiation-induced high temperature on the fruit surface plays a critical role in the fruit quality rather than the plant temperature due to degradation of lycopene (Dumas et al. 2003). For this reason, greenhouse-grown tomatoes have 40% more lycopene than the field-grown tomatoes (Helyes et al. 2007).

21.3.4 Terpenoids

Apart from affecting the bioactive components, high temperatures also alter the volatile aroma compounds in grapes. At 35°C, pigment development was completely inhibited in Tokay and reduced in Cardinal and Pinot Noir grapes compared to 20°C or 25°C. High temperature reduced the synthesis of monoterpenes especially linalool responsible for the Muscat flavour (Zemni et al. 2005).

Effect of high temperature on the soybean isoflavone quality was found to alter with the addition of elevated CO_2 and water stress (Caldwell et al. 2005).

21.4 Effect of Water Stress

Water is the most limiting factor in crop production, and consequently, drought stress is very frequently encountered by all the crops. It has become a major constraint for food production especially in areas where cultivation depends on rains. Many fruits crops are widely cultivated in semi-arid climates.

21.4.1 Vitamin C, Sugars and Acidity

Water stress, depending on the stage of occurrence, affects the sugar content of fruits to a greater extent than other quality parameters. In fruits, water stress reduces the juiciness, thereby increasing the sugar content (Chartzoulakis et al. 1999). However, the effects are primarily dependent on the phenological stage of water stress and may make fruits completely non-commercial (Romero et al. 2006). Deficit irrigation treatment is used in some of the fruit crops to increase the sugar content by imposing the treatment at later stages of fruit maturation. This resulted in higher content of TSS, total phenolics, glucose and sucrose in mandarin trees (Navarro et al. 2010; IvánGarcía-Tejero et al. 2011). Apart from sugars and acidity, deficit irrigation effect on other parameters like ascorbic acid and nutraceuticals is minimal (Buendia et al. 2008; Aguado et al. 2010). Higher total soluble solids and sugars were seen in tomato under deficit irrigation conditions (Mitchell et al. 1991; Birhanu and Tilahun 2010; Metin Sezen et al. 2010). However, marketable yield of tomato decreases due to water stress.

21.4.2 Phenols, Flavonoids and Anthocyanins

Phenolic compounds are secondary metabolites synthesised in response to biotic or abiotic stresses (Materska and Perucka 2005). Water stress increased the anthocyanin and tannin content of the skin and sugar concentration of berries in grapes, but seed tannin content was not affected by the water stress (Roby et al. 2004). Response of phenol production to water stress was used to increase the antioxidant quality of strawberries by adopting deficit irrigation methods (Buendia et al. 2008). Deficit irrigation increased the accumulation of anthocyanins and proanthocyanidins in strawberries. Increase in the anthocyanins and phenolic compounds is mainly due to the enhanced activity of phenylalanine ammonia-lyase enzyme under water-limiting conditions (Tovar et al. 2002).

Increase in the phenol content of fruits depends on the stage of deficit irrigation. Reduced irrigation during fruit maturation stage enhances the total phenols in fruits (Navarro et al. 2010). However, lack of water during fruit set and early fruit growth is going to adversely affect the quality. Mineral movement like nitrogen, potassium and phosphorus within the tree is going to be affected by the water stress (Kirnak et al. 2001). This will affect the fruit quality if occurs during the active fruit growth periods.

21.4.3 Lycopene and Carotenoids

Carotenoids, the naturally occurring isoprenoids with antioxidant properties, are the major pigments in many fruits and vegetables. Buendia et al. (2008) studied the influence of Regulated Deficit Irrigation (RDI) on the content of carotenoids in strawberry. RDI caused fruit peel stress, lowering the content of carotenoids. Navarro et al. (2010) reported that deficit irrigation treatment in Clemenules mandarin citrus trees grafted on Cleopatra and Carrizo rootstocks stressed during phase III (later stage of fruit maturation) had greater lycopene content compared to control fruits.

21.5 Salinity Stress

Salt stress is one of the important environmental factors that reduce growth, yield and production of plants. Salt stress during fruit production has been found to limit vegetative growth and fruit quality.

21.5.1 Phenols, Flavonoids and Anthocyanins

Salt stress is known to induce the formation of reactive oxygen species and their scavengers, enzymes or nonenzymatic low molecular mass antioxidants. Higher production of ascorbic acid, anthocyanins and superoxide dismutase and accumulation of selected minerals were observed in both sensitive cv. Elsanta and less sensitive cv. Korona varieties (Keutgen and Pawelzik 2009). The response of strawberry plants under salt-stress conditions revealed that the phenylpropanoids and flavonoid pathways are still intact and functioning, as indicated by higher contents of antioxidants (Neocleous and Vasilakakis 2007).

21.5.2 Lycopene and Carotenoids

Antioxidants like lycopene, carotenoids and ascorbic acid accumulated in tomato fruits during salt stress (D'Amico et al. 2003). However, in leaves of *Lycopersicon esculentum* plants under salt-stress condition shows a decreased expression of carotenoid biosynthetic genes thus plays a significant role in hampering photosynthesis rate and thereby reduces the yield and the productivity of plants (Merlene Ann Babu et al. 2011).

The influence of abiotic stresses has got a tremendous bearing on the antioxidant quality of fruits. The response depends on the crop species and the phenological stage at which the stress occurs. The impact of abiotic stresses on antioxidant quality becomes still more relevant under the climate change conditions. Hence, efforts need to be made to understand the effect of various abiotic stresses on different fruit crops and the critical stages of fruit growth at which the fruit overall quality is adversely affected and to develop strategies to overcome the adverse impacts of abiotic stresses.

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Urban Landscapes for Carbon Sequestration in Climate Changing Scenario

22

Holalkere Puttaswamy Sumangala

Abstract

Increasing concern about climate change and global warming has created immense awareness among society about greenhouse gas and its reduction. Irrespective of the geographical location, population density and economic development of any region, there is a huge scope for addressing the greenhouse gas emission. It is, however, an opportunity for the local body to apply the concept of urban green space management for the reduction of atmospheric CO_2. Cities have a key role to play in the global agenda for addressing the challenge of climate change. Today, approximately half of the world's population lives in cities; by 2050, that proportion will probably have increased to two-thirds. India has the highest rate of change of the urban population and will remain above 2% annually for the next three decades. At this rate, an estimated 854 million people will live in Indian cities by 2050. Urban greenery is one of the ways to bridge this gap between urbanisation and nature. Trees and other ornamental plants are crucial to the sequestration of carbon from atmosphere and play an important role in reducing carbon footprint. Urban green spaces constitute critical biodiversity hotspots in densely crowded, concrete-dominated city environments. Even though green spaces play vital role in mitigating the climate change, they remain little studied. The green space needs to be strategically planned. Cultivating urban green spaces is becoming inevitable for clean and green environment in urban areas.

22.1 Introduction

There is general consensus among experts that if temperatures will increase, there will be more dramatic events such as floods and storms, summers will be warmer and drier, winters will be warmer and wetter and sea levels will rise.

According to UN reports, India has the highest rate of change of the urban population and will remain above 2% annually for the next three

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decades. At this rate, an estimated 854 million people will live in Indian cities by 2050. Without careful planning, cities will be overwhelmed with environmental challenges. Plants offer a great extent of environmental and ecological services along with aesthetic values. Trees and other ornamental plants are crucial to the sequestration of carbon from atmosphere and play an important role in reducing carbon footprint (Brethour et al. 2007). The green space needs to be strategically planned. Cultivating urban green spaces is becoming inevitable for clean and green environment in urban areas. Clear guidance is needed for local authorities and other practitioners on how best to manage public urban green spaces in order to respond to climate change.

Urban habitats, a neglected ecosystem, are the principal concern to maintenance of biodiversity and ecosystem services. Research has shown that large trees can absorb significant amounts of carbon dioxide, particulate matter and other pollutants from the atmosphere each year and release oxygen through photosynthesis. As such, trees and other landscape plants serve as an important tool in improving air quality in cities and mitigating potential health hazards on humans. In recent days urban green spaces have gained popularity by ideas like green buildings, greenbelt, green roofs and energy conserving landscape and using ideal plants for air, sound and water and soil pollution mitigation. Parks and urban green spaces improve people's health by providing them with better environment.

At this juncture, cities need to be designed with more green spaces in order to provide clean and green environment. The intelligent landscape management can reduce water, air and soil pollution.

22.2 Effect on Urban Areas

Urban areas, where the majority of the population live, will warm more than rural ones because of heat liberation by buildings. There are significant temperature differences between urban and periurban areas, and surface temperatures can be up to 6°C greater in high-density suburbs compared to low-density suburbs. The concentration of buildings in urban areas leads to the formation of a specific climate characterised by higher night-time temperatures, restriction of wind which disperses pollutants and increased run-off, i.e. 'urban heat islands'. Climate change provides opportunities as well as threats for urban green spaces. For example, it provides an opportunity to remodel or create outdoor spaces. Urban green spaces also play a role in improving air quality and preserving biodiversity.

Cities constitute a habitat and home for an increasingly large proportion of the world's population, playing a critical role in maintaining ecological, economic and social wellbeing. Unlike protected forests, city parks constitute green spaces managed largely for recreational purposes and form the largest proportion of publicly available green space for urban dwellers (Oleyar et al. 2008). Urban green spaces may provide better social and psychological functions that substantially improve the quality of city life (Botkin and Beveridge 1997; Long and Nair 1999; Chaudhry and Tewari 2010a; Aminzadeh and Khansefid 2010).

Despite the importance of these green spaces, they are not studied in most parts of the world (Cornelis and Hermy 2004; Davies et al. 2008; Weifeng et al. 2006; Clarke et al. 2008).This lack of understanding of biodiversity distributions and dynamics in urban parks makes it very difficult to plan strategies for urban conservation (Alvey 2006; Weifeng et al. 2006; Jim and Chen 2009). Studies on urban forestry including urban parks have largely been conducted in North America and Europe, with comparatively few studies from other parts of the world (Fernández-Juricic and Jokimäki 2001; Cornelis and Hermy 2004). Few studies conducted in the Asia/Pacific have also largely focused on Australia, Southeast Asia and Russia (Jim and Liu 2001; Weifeng et al. 2006; McKinney 2008), with very little information on about urban forests and specifically on urban parks in South Asia (Nagendra and Gopal 2010; Singh et al. 2010).

22.3 Adaption and Mitigation

Urban green spaces can mitigate the impacts of climate change through absorption of pollutants, including greenhouse gases. Green spaces also help in water conservation and in reducing the temperature.

A London study found that the temperatures to be, on an average, 0.6°C cooler in the park than in neighbouring streets over a 12 h period. Shopping street with no shading was 3°C warmer than the centre of the park (CURE 2004). Work in Greater Manchester found that the surface area of woodland was 12.8°C cooler than the town centre. Modelling work based on Manchester study suggested that adding 10% green cover kept the maximum surface temperatures in high-density residential areas and town centres on the hottest summer days at or below the 1961–1990 level. However, removing 10% green cover from these areas increased maximum surface temperatures by up to 8.2°C by 2080, assuming the highest emissions scenario (AUSCCUE WP). According to Upmanis (2000), even small spaces can have a cooling effect; parks of 1 or 2 ha have been found to be 2°C cooler than surrounding areas. The extent of the cooling effect is greatest when temperatures outside the park are highest. Research based on Tel Aviv found that the cooling effect of green space can be felt up to 100 m from the site and the shape of green space can have an impact on cooling (CURE 2004). Green spaces that lie higher than the surrounding land achieve wider influence, as do those with greater tree cover. For example, green corridors can be used to channel air into a city from surrounding forested slopes (Loesner 1978).

Trees, when located close to buildings, can act as natural air conditioners and provide cooling through evapotranspiration and therefore reduce energy consumption required to maintain temperatures. Research on Merseyside found that places where vegetation cover is 50% were cooling by 7°C than areas where there was 15% vegetation cover (Whitford,et al 2001). Research in Camden and Newark showed that planting trees in urban areas is a viable and economically efficient way of reducing urban heat islands (LCCP 2006). A mix of conifers and deciduous trees would be preferable for year-round benefits. The shade provided by mature trees can keep surfaces cooler by as much as 15.6°C (Gill et al. 2007). Hard surfaces increase the rate and volume of run-off of rainwater, resulting in flash flooding. Green space can help with water management as it provides a permeable surface, reducing surface run-off into drains, and therefore lowers the risk of flooding during peak flows.

According to Gill et al. (2007), modelling based on Greater Manchester suggested that increasing green cover by 10% in residential areas reduces run-off from these areas by 4.9% in the highest rainfall scenarios predicted in the 2080s. Increasing tree cover by a similar 10% would reduce run-off by 5.7%. However, green space alone will not be able to cope with the estimated increases in rainfall and subsequent run-off, so storage provision for run-off also needs to be considered. Specifically, ponds and other bodies of water can be used for water storage, and water surfaces stay cool during droughts (ASCCUE 2012). In addition dry ponds and grassed areas could be used to store flood water (CURE 2004). Sutcliffe Park in Greenwich took an innovative approach to flood management and de-culverted a river in an underused park. This additionally brought social benefits as the number of visits to the park increased and the park had a more natural habitat (Goode 2006).

The ecosystem is finely tuned with plant and animal species highly interdependent on each other for survival. Urban green spaces provide valuable habitats for animals and plants but species can respond strongly to environmental change. There is a need for wildlife corridors within towns and cities to help plants and animals move in response to climate change. Urban areas need to be permeable to wildlife; private gardens as well as parks and other urban green spaces including verges can help with this. The existence of water areas can also encourage biodiversity. Although the main climatic benefits of urban green space are cooling and shading, vegetation and soils, particularly trees, can counter poor air quality by absorbing greenhouse gases such as carbon dioxide and other air pollutants and can act as ‘carbon sinks’. This can be especially effective if trees are located close to a pollution source (Brown et al. 2001). Soils will generally also store carbon, especially rich, organic soils such as peat.

According to Broadmeadow and Matthews (2003), different types of trees absorb different levels of pollutants. A healthy semi-mature Douglas fir forest can absorb 4 t of carbon per hectare per year, compared to around 2.5 t for beech. Stock diversity is needed to ensure long-term survival (NUFU 2005). Some experts suggest large areas of green space to have a significant mitigation effect and, as trees release carbon when they are burnt or rot, may only act as a temporary means of carbon storage. Similarly, when soils are disturbed, they will also lose their carbon content to the atmosphere as carbon dioxide.

In the UK half a hectare of woodland over one rotation could compensate for the car fuel consumed over an average driver's lifetime (Broadmeadow 2006). It is estimated that an area the size of a football pitch would be needed to counter the CO_2 emissions of an average person in the UK (NUFU 2005). Vegetation can be used to cool buildings, thereby reducing the need for mechanical air conditioning (Gill et al. 2007). US research found that shelter and shade from trees can save up to 10% of energy needed to heat and cool nearby buildings. Research in the UK suggested that savings for a residential property might be about 3%. To a lesser extent, the use of allotments and community gardens to grow fruit and vegetables could help reduce food miles, albeit on a relatively modest scale, which would again reduce carbon emissions. In another study, vegetation has been shown to lower wall surface temperatures by 17°C, which led to a reduced air conditioner use by an average of 50%. Planting trees and other ornamental plants around a building can significantly reduce the extreme temperatures in the ambient environment, thus lowering the energy cost of heating and cooling and, in turn, reducing its environmental burden (Bowler et al. 2010). Thus, planting trees around buildings is not only a positive step towards reducing energy consumption, but it also has a significant financial benefit as well.

Urban green spaces are the most effective means of removing atmospheric pollution in big cities. In a study undertaken in 55 cities of the USA, it was found that environmental pollution worth more than 700,000 t per year valuing US $ 3.8 billion was removed by the vegetation (Nowak et al. 2006). Vegetation of Guangzhou City, China, consisting of 7,360 ha of urban forests removed 312 t of atmospheric pollution annually (US $ 11,000), out of which particulate matter accounted for 234 metric tons (Jim and Chen 2008). 2.4 million urban trees (over 300 sq km) of Beijing, China, with 4.5 million population were responsible for removal of 1,261 t of environmental pollution annually, out of which 776 million were particulate matter (Yang et al. 2005).

Cities strongly influence the carbon cycle and emitting large amounts of CO_2. It is possible to remove atmospheric CO_2 by sequestering it in urban green spaces. As part of the EU PLUREL project, the study adopted a carbon footprint approach to assess the level of sequestration of a recently created green belt in Leipzig, Germany. The green belt is 2.16 ha in area and about 600 m long. It is partly planted with dense blocks of trees and partly open land. The study assessed CO_2 sources and sinks throughout the life cycle of the green belt project, assuming a 50-year lifetime. It did not include carbon involved during the growing of trees in nurseries or the carbon stored below ground because there is a lack of consensus on how to estimate these values. The carbon footprint was estimated according to three life cycle stages: construction, maintenance and storage in trees. Construction emissions were those caused by transporting trees, workers and equipment, as well as emissions from planting. Maintenance emissions arose from pruning, thinning of trees for safety, grass cutting and transporting workers and machinery for maintenance. This includes the removal of dead trees (including transport) which are then turned into wood chips, the transportation of grass clippings to a recycling plant and the clearing of the root zone with a trimmer. There was no fertilisation of the site and only irrigation was given in the case of extreme drought situations. The amount of carbon stored in the trees themselves was derived from rates of tree growth and mortality. Emissions from construction were estimated to account for 4.8 t of CO_2 per hectare, mainly from transport (33%) and excavating holes for planting (47%). Emissions from maintenance after 50 years ranged between 2.57 t of CO$_2$ per hectare in the case of minimum tree growth and low mortality and 4.71 t of CO$_2$ per hectare in the case of maximum tree growth and high mortality. Greater tree growth and high tree mortality increases emissions because more maintenance is needed for the upkeep of the growing trees and to remove the dead ones.

The carbon stored in trees varies with growth and mortality, but maximum growth and low mortality stores large amounts of carbon at 226 t of CO$_2$ per hectare. Only 38 t of CO$_2$ per hectare is stored with minimum growth and high mortality. In total, when the emitted and stored carbon are balanced against each other, the footprint ranged from 29 to 218 t of CO$_2$ sequestered per hectare, depending on level of mortality and tree growth. The study indicated that this amount would increase if there were ground cover that requires no mowing, such as ivy, and an optimum number of trees that require no thinning and would decrease if the space was an open park design. Lawn without trees would make the green space a source of CO$_2$.

To put the footprint into perspective, mitigation of all emissions from residents of the local district for 50 years would require a total area of 14,800 ha, which is roughly 50% of the city area for just 1.5% of the city population.

22.4 Turfgrasses

The amount of carbon storage depends on many variables including plant growth, plant type, soil type, management and environmental conditions. In grass systems, both fertilisation and irrigation have been shown to increase C sequestration levels. This is due to an increase in plant biomass within the soil, which in turn increases the amount of soil converted to carbon through humification (Contant et al. 2001). Grasses also provide permanent ground cover, leaving the soil underneath relatively undisturbed. This reduces soil erosion and keeps carbon stable within the soil. Turfgrasses have the potential to sequester C but needs more studies.

The estimated carbon pool for US urban soils is 77 ± 20 mg C ha^1. Converting previous agricultural land into perennial grasses sequesters 0.3 mg C ha^1 year and can increase to 1.1 mg C ha year with fertiliser and irrigation management. Qian and Follett (2002) modelled soil organic carbon sequestration with historic soil testing data from golf courses and reported that golf course soils sequester SOC at a rate of 1.0 mg ha^1 year^1. All of these C sequestration rate studies included sampling of less than or equal to 30 cm of the top soil. Current research by Qian and Follett (2010) compared fertilised fine fescue (Festuca spp.) (irrigated and nonirrigated), Kentucky bluegrass (*Poa pratensis* L.) (irrigated) and creeping bent grass (*Agrostis palustris* Huds.) (irrigated) for differences in soil organic carbon (SOC) rates. Irrigated fine fescue added the most SOC at the 0–20 cm depth (3.35 Mg C ha^1 year^1). The additions from nonirrigated fine fescue, Kentucky bluegrass and creeping bent grass were 1.39, 2.05 and 1.73 mg C ha^1 year^1. Irrigation increased the amount of C sequestration. All turfgrass species were found to exhibit significant amount of C sequestration over the 4-year researching period. On a per hectare basis, urban turfgrasses have the potential to sequester greater amounts of C than cropland systems and greater than or equal amounts of C as forest systems. Although turfgrasses may sequester more C than other land uses, the amount of land covered by urban turfgrasses is small when compared to the amount of land covered by cropland and forestland (in the USA).

Even though turfgrasses sequester C, fossil fuel use is directly and indirectly associated with lawn management practices such as mowing, fertilising, pesticide application and irrigation. Using conversions for C emissions by Dr. Lal from Ohio State University, all energy use can be converted into carbon equivalents (CE). Mowing consumes gasoline (0.84 kg CE kg^1 gas); fertiliser and pesticides require production, transportation, storage and transfer (0.1–12.6 kg CE kg^1 fertiliser or pesticide); and irrigation requires pumping (CE depends on the type of irrigation system). Master's research by Gina Zirkle and Dr. Lal modelled C sequestration for home lawns in the USA and compared that to the CE of management practices (Zirkle 2010). CE for lawn management practices were only 10–20% of the total

C sequestration rate. Therefore, home lawns still sequestered 80–90% of the SOC when management practices were subtracted from the total C sequestration potential. However, the amount of energy required to maintain turf may be different in other turfgrass ecosystems (examples include golf courses and sports fields). Selhorst (2007) found that farmland converted to golf courses in Ohio sequesters C at an initial rate of 2.5–3.6 mg C ha^1 year^1. This high rate is most likely due to the increase in fertiliser and irrigation management, as well as supplying a permanent ground cover for the soil. Management practices were also evaluated, and it was found that golf courses sequestered carbon up to 30 years before management practices offset the sequestration potential. Soil organic carbon (SOC) sequestration and the impact of carbon (C) cycling in urban soils are themes of increasing interest. A model was developed to investigate the potential of C sequestration in home lawns. The model contrasted gross carbon sequestered versus the hidden C costs (HCC) associated with typical lawn maintenance practices. The potential of SOC sequestration for US home lawns was determined from SOC sequestration rates of turfgrass and grasslands. Net SOC sequestration in lawn soils was estimated using a simple mass balance model derived from typical homeowner lawn maintenance practices. The average SOC sequestration rate for US lawns was 46.0–127.1 g Cm^{2}year^1. Additional C sequestration can result from biomass gains attributable to fertiliser and irrigation management. Hidden carbon costs are the amount of energy expended by typical lawn management practices in grammes of carbon equivalents (CE)/m^2/year and include practices including mowing, irrigating, fertilising and using pesticides. The net SOC sequestration rate was assessed by subtracting the HCC from gross SOC sequestration rate. Lawn maintenance practices ranged from low to high management. Low management with minimal input (MI) included mowing only, a net SOC sequestration rate of 25.4–114.2 g Cm^{2}year^1. The rate of SOC sequestration for management by homeowners was 80.6–183.0 g Cm^{2}year^1. High management, based on university and industry-standard best management recommendation practices, had a net SOC sequestration rate of 51.7–204.3 g Cm^2 year^1. Lawns can be a net sink for atmospheric CO$_2$ under all three evaluated levels of management practices with a national technical potential ranging from 25.4 to 204.3 g Cm^{2}year^1 (Gina Zirkle et al. 2011).

22.5 Urban Green Spaces: The Indian Situation

Research in this direction is still primitive stage in India. Documented information on role of urban landscape/urban green space is not available. Few initiatives in this direction has been gathered and presented here.

The National Mission for a Green India, as one of the eight missions under the National Action Plan on Climate Change (NAPCC), recognises that climate change phenomena will seriously affect and alter the distribution, type and quality of natural resources of the country and the associated livelihoods of the people. The mission (henceforth referred to as GIM) acknowledges the influences that the forestry sector has on environmental amelioration through climate mitigation, food security, water security, biodiversity conservation and livelihood security of forest-dependent communities.

Over the past decades, national policies of conservation and sustainable management have transformed the country's forests into a net sink of CO$_2$. From 1995 to 2005, carbon stocks stored in our forests are estimated to have increased from 6,245 mt to 6,622 mt, thereby registering an annual increment of 37 mt of carbon or 138.15 million tons of CO$_2$ equivalent. This annual removal by forests is enough to neutralise 9.31% of total GHG emission in the year 2000.

Through the scientific modelling done using RCM (regional climate model) and BIOME model (BIOME 4), it was observed that more than 50% of the vegetation in India would find it less than optimally adapted to its existing location by 2085, making it more vulnerable to the adverse climatic conditions as well as to the increased biotic stresses of already challenged forest ecosystems. The forests would be vulnerable on account of the altitudinal and latitudinal shift of the species of the forest ecosystems and also on account of increased occurrences of fire, pest/diseases, invasive species, change in species assemblage/forest type, forest dieback and loss of biodiversity. Most of the Indian cities, with the exceptions of Gandhinagar and Chandigarh, are far behind in per capita urban forest availability in comparison to European,, Australian and American cities, e.g. average green cover is about 19% for 22 largest Dutch cities (about 228 m^2per capita); estimated per capita green space availability in Canberra, Australia and Greater Paris region is 80 m^2. The Maidan of Kolkata, Ridge of Delhi, Lal Bagh of Bengaluru and City Forest of Srinagar are some of the examples of well-managed urban green spaces that serve as green lungs and harbour immense diversity.

In India, except for a few cities, urban forests/green spaces are not well studied. There are, however, some studies on Bangalore (Sudha and Ravindranath 2000; Nagendra and Gopal 2010), Chandigarh (Chaudhry 2006; Chaudhry and Tewari 2010a) and Delhi (FSI 2009). Some issue-specific studies such as biodiversity and carbon storage are also available for Bhopal (Dwivedi et al. 2009), Delhi (Khera et al. 2009), Jaipur (Verma 1985, Dubey and Pandey 1993), Mumbai (Zerah 2007) and Pune (Patwardhan et al. 2001). A few studies are also available for specific locations within the urban ecosystems, such as NEERI Campus, Nagpur (Gupta et al. 2008) and Indian Institute of Science Campus, Bangalore (Mhatre 2008). The most robust studies on urban forests using satellite imageries have been for Delhi and Chandigarh. The estimates suggest that Chandigarh and Delhi have 35.70% and 20.20% urban forests, respectively (Action Plan 2009–10 and FSI 2009). When it comes to urban green spaces, Delhi stands apart. Delhi is one of the biggest metropolises of India, second largest by area and third largest by population. New Delhi is rated as one of the greenest capital cities in the world with a large number and variety of parks and gardens. The green cover of Delhi has expanded from 2% to more than 20%, i.e. from 22 sq km to about 300 sq km in the past 20 years or so. The Delhi Ridge (actually the tail end of Aravalli Range) runs through South Delhi and terminates in Central Delhi and is often referred to as city's green lungs. Owing to its green spaces, Delhi has become home to a large number of birds and is now recognised as the world's most bird-enriched capital, only after Nairobi in Kenya.

Delhi has successfully recreated two important repositories of regional biodiversity, namely, Yamuna Biodiversity Park and Aravalli Biodiversity Park. Delhi is currently debating with its future pattern of growth—horizontal or vertical. Naturally this choice will also depend on the nature and pattern of green spaces in Delhi, as typically vertical cities tend to have more public greens, while horizontal sprawls end up providing the luxury of private green spaces as well.

Bangalore is an interesting case of the fastest growing city in India, which spread from 2 km^2 in 1537–360 km^2 in 1994. With respect to tree vegetation, tree crown cover of the city has shown a decline from 1912 to 1980. But, during the period 1980–1985, there has been an increase in crown cover from 3.8% to 19.9% of the land area (Behera et al. 1985). A comprehensive study on urban forests of Bangalore found 374 species in the different land-use categories. Species richness was found highest in parks (291 species), followed by residential areas (164), institutions (126), temples (107) and commercial areas (Sudha and Ravindranath 2000). Although, density of street trees in Bangalore is lower than many other Asian cities, the species diversity is high (Nagendra and Gopal 2010). Green infrastructure supplies a route to climate change adaptation that can be applied across a range of urban settings, helping to reduce urban temperatures and carbon emissions. However, it is important to ensure that local conditions are properly considered and planned for. As such, green infrastructure represents the state of the art and the high level of adaptability required to cool our cities for decades to come.

22.6 Future Research Needs

- There is need for intensive research on urban green spaces to understand the dynamics of CO_2 sequestration by different types of plants.
- Research is required in minimal maintenance gardens in climate change scenario.

- Studies are required in identification of native plant species tolerant to biotic and biotic stress.
- Development of models for higher carbon sequestration in residential gardens, terrace or roof top gardens and public parks.

22.7 Conclusions

Urban habitats, a neglected ecosystem, are the principal concern to the perspective that includes the activities of humans in the provision and maintenance of biodiversity and ecosystem services. The urban green space needs to be strategically planned. The priority for planners and green space managers is to ensure that green space concept work properly. Action is needed now to steer urban development towards green cities that contribute to environmental security and help in carbon sequestration in cities.

Climate change is expected to place increasing stress on urban areas. Minimising its impacts through adaptive measures is therefore unavoidable. Worldwide studies have shown that urban landscapes can contribute in big way for carbon sequestration either in the form of soil organic carbon by turfgrasses or in the tress.

Problems like soil erosion, river flooding and lack of biodiversity are frequent in urban contexts. Green spaces when properly planned can reduce these problems and increase the ground water recharge.

Aesthetically planned surroundings are not a luxury anymore but form one of the basic necessities of life due to its environmental benefits. Thus urban landscaping deserves due importance in research priorities and policy planning for better urban environments and carbon sequestration.

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23

Impact of Climate Change on Insect Vectors and Vector-Borne Plant Viruses and Phytoplasma

Manem Krishnareddy

Abstract

Plant virus and phytoplasma diseases are emerging as a serious constraint in improving productivity of horticultural crops. Ecological factors, including migration, climate and agricultural practices are considered to play an important role in the emergence of plant virus diseases. Changing climate conditions can contribute to a successful spread of newly introduced viruses or their vectors and establishment of these organisms in areas that were previously unfavorable. A number of plant viruses are transmitted by vectors, many of them are not able to establish at current climate conditions. The most important vectors such as Aphid, whitefly, thrip, and leaf hoppers which are associated with potyviruses, begomoviruses, tospoviruses and phytoplasma, have emerged during the last two decades. Plant virus diseases and vectors are strongly influenced by weather and climate. The temperature and moisture conditions interacting with seasonal phenology, and stress on the host determine infection severity and distribution. Increasing international travel and trade of plant materials enhances the risk of introducing new viruses and their vectors into production systems. However, climate change is expected to have effects on their establishment, spread and reproduction potential as well as on the vector transmission. If climate change increases or decreases environmental conduciveness, the shift in selection pressure on the host populations could result in shifts in the diversity of resistance genes present. Recent observations have shown that resistance to bhendi yellow vien mosaic virus tends to break when okra is grown at higher temperatures. These climatic changes affect the biological and ecological characteristics of insect species, through direct effects on the physiology of organisms and through indirect effects on their habitat. The number of disease epidemics

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has dramatically increased in recent years, as have the threat of emerging new diseases and the reemergence of other diseases. Some of the recent examples are incidence of thrips transmitted tospoviruses and whitefly transmitted begomoviruses in chilli, cucurbits, okra and tomato. Different biotypes of an aphid or whitefly species have been associated to outbreaks and expansions of viral diseases. The other biological changes involved include introduction of new, more efficient virus-vector species and more efficient virus-vector biotypes or variants of existing vector species, and circumvention of host defenses in introduced crops. At the molecular level the genome alterations most likely to occur in different emerging viruses are those caused by recombination, pseudo-recombination, reassortment and modular evolution. Numerous factors have been cited as potential drivers of the emergence of viral outbreaks, including pathogen introduction through global traffic, changes in vector populations, genetic recombination, new farming techniques, changes in weather conditions. As a first and necessary step in obtaining baseline information about climate change impact on different virus diseases and vectors, a survey should be conducted among growers and plant protection officers. The survey will define a list of most important climate-related plant viruses and vectors for specific regions. Awareness of forthcoming significant climate change it is necessary to work out the impact to be able to make predictions.

23.1 Introduction

Global warming is one of the principal challenges facing agriculture, plant pathogens, and insects worldwide. The average global warming trend over the last 50 years is almost twice that of the last 100 years (IPCC 2007). Increases in mean temperature lead to an increased risk of high temperature extremes, such as intense, long-lasting, and more frequent heat waves. Increases in mean precipitation in the tropics, accompanied by greater intensity of precipitation, could lead to flooding, whereas widespread decreases in mean precipitation mid-latitudes bring an increased risk of drought. Likely increases in incidences of wind disturbances are predicted to contribute to a greater number of storms and more intense tropical cyclones (Meehl et al. 2007).

As a consequence of climate change, already challenged global food supply is likely to be further threatened (Beddington 2010; Lobell et al. 2008; Rosenzweig et al. 2001), and crop losses due to pests and diseases are already considerable. One of the consequences of climate change is the increase in production losses caused by some pests and diseases (Burdon et al. 2006; Garrett et al. 2006, 2010; Easterling et al. 2007; Chakraborty et al. 2008; Jones 2009; West et al. 2012). The causes of these involve complex interactions. Complex relationships between host plant, pest, pathogen, and environment create uncertainty particularly involving vector-borne diseases (Finlay and Luck 2011). Global warming affects individual species and interactions between species by directly affecting their physiology and indirectly their habitat (Hulle et al. 2010). Plant virus and phytoplasma diseases constitute one of the limiting factors to the productivity of agriculture. Changes in host plants and insect vector populations that might result from climate change could affect the spread of plant viruses. At the individual level, alterations in plant physiological processes that are relevant to their molecular interactions with viruses, like changes in metabolism, leaf temperature, and their effects on some processes, like the temperature-sensitive antiviral resistance based in RNA silencing, can also influence the ability of individual plants to control viral infections (Canto et al. 2009).

There is already evidence of recent climatic changes affecting a broad range of organisms with diverse geographical distributions (Parmesan and Yohe 2003; Parmesan 2006; IPCC 2007). Nonnative plant and insect species from adjacent areas may shift their distribution ranges and become new elements in communities where they were previously not present. These may include species that might constitute reservoir hosts or vectors for plant viruses, capable of causing epidemics in nearby crops. In addition, global warming may cause alterations in the densities of already present alternative hosts to viruses. Changes in host and vector phenology can also have effects on the probability of contact between viruses and hosts: the sooner a reservoir host is available to vectors for virus transmission, the higher the probability of initial infection foci in crops. Furthermore, there are also important differences in virus–vector relationships that affect the temporal and spatial dynamics of virus epidemics. For example, transient species are often the main vectors of viruses that are transmitted quickly during brief probes, while colonizing species are the main vectors of viruses that require longer feeding times and often direct contact with vascular tissues. Depending on the manner of transmission, a change in environmental conditions will have different consequences on the spread of a virus.

23.2 Insect Vectors of Plant Viruses and Phytoplasma

Sucking insects, such as aphids, thrips, whiteflies, and leaf hoppers, are associated with the transmission of viruses, which can lead to major crop losses. The insect transmission of plant viruses can be classified as persistent, semi-persistent, or nonpersistent. Persistent transmission requires sustained feeding by the insect, while nonpersistent transmission is dependent on a more superficial relationship between the insect and the plant.

Most of the known plant viruses are transmitted by insect vectors and are entirely dependent on the behavior and dispersal capacity of their vectors (Nault 1997; Ng JCK and Falk 2006). Insect vectors of plant viruses belong to several orders like Hemiptera, Coleoptera, Thysanoptera, Orthoptera, Dermaptera, Lepidoptera, and Diptera, but Hemiptera is by far the most important group of vectors of plant viruses. The order is divided into three suborders: Heteroptera (or true bugs), Auchenorrhyncha (hoppers), and Sternorrhyncha (aphids, whiteflies, mealybugs, psyllids). Most of the vectors of plant viruses are included in the latter two suborders and are referred to here as homopterans which include both Auchenorrhyncha and Sternorrhyncha (Richards and Davies 1977). One of the differences between homopterans and heteropterans is in the way they insert their mouth parts into plant tissue.

Homopterans are vectors of about 55% of all known plant viruses (Nault 1997), and the main vectors according to the number of virus species transmitted belong to the families Aphididae (aphids) and Aleyrodidae (whiteflies). Aphids transmit more than 50% of the plant viruses vectored by insects (Nault 1997), while whiteflies transmit 114 virus species within five different virus genera (Jones 2003). Both groups of vectors are very well adapted for virus transmission because their stylets frequently pass between cells to reach the target tissue—the phloem—and can penetrate cells without causing damage. The larger stylet bundles of Heteroptera and Auchenorrhyncha are more likely to take an intracellular path and cause significant damage to plant tissues en route, which reduces the chances of virus infection (Mitchell 2004). Furthermore, the high rates of population increase, the short life cycle, and high dispersal potential make aphids and whiteflies the main group of vectors of plant viruses. Many of these cause severe yield losses and have a great impact on agriculture throughout the world (Fereres and Moreno 2009; Pappu et al. 2009; Mandal et al. 2012).

Temperature is the key climate parameter that influences the occurrence and the density of insect vectors (Bale et al. 2002). Mean autumn and minimum winter temperatures have been identified as key factors for the establishment of field populations of Mediterranean mealybug species (Peacock et al. 2006), while rising summer temperatures are likely to favor the development and population density of endemic potential vectors. The alternative overwintering strategy of some mealybug species, for example, *Heliococcus bohemicus*, that hibernate either as adult females or as second instar larvae might be a measure to adapt to different abiotic conditions and could favor survival of field populations. Species that are able to hibernate in their active stages show increased winter survival in warm winters (Bale et al. 2002). Considerable increases in minimum winter temperatures have been reported for northern and central Europe (Heino et al. 1999).

23.2.1 Impact on Aphids and Aphid-Transmitted Viruses

Insects are the most common vectors, and among these, aphids account for the transmission of 50% of the insect-vectored viruses (Nault 1997). Aphids are exquisitely designed for their roles as vector. Piercing–sucking mouth parts facilitate the delivery of virions into plant cells without causing irrevocable damage. With the option of asexual reproduction, aphid populations can increase at extraordinarily high rates, thereby potentiating disease epidemics and furthering the short- and long-distance spread of viruses. Additionally, aphids are globally distributed, and there are more than 200 vector species identified (Nault 1997; Ng and Perry 2004; Braust et al. 2010).

The majority of aphid vectors belong to the subfamily Aphididae (order: Homoptera). Aphid vectors are also found in nine other subfamilies, but they account for only a very small proportion of those that are known to transmit viruses. A number of unique features contribute to the success of aphids as vectors of plant viruses. These include (1) a polyphagous nature for some aphid species (*Myzus persicae*) that allows them to feed on a wide range of plant hosts, a property important for the dissemination of viruses that infect a large number of plant species; (2) the ability to undergo parthenogenetic reproduction, thus facilitating the rapid production of large quantities of offspring; and (3) the possession of a needlelike stylet capable of piercing plant cell walls and delivering viruses into a host cell. Feeding behavior and host plant selection by an aphid will affect its potential as a vector (Harris and Maramorosch 1977). The extent to which these factors influence virus transmission will depend on the specific virus and its mechanism of transmission. Understanding the spread and control of viral diseases requires an understanding of the vector and its behavior; vector transmission is paramount to epidemiology (Ng and Perry 2004). Aphids show a considerable variation in their life cycle traits and even within species variation can be very high. Some species, termed holocyclic, respond to the oncoming winter with a sexual phase, often placing eggs on woody plants. Anholocyclic aphids, on the other hand, do not go through the sexual phase and continue with parthenogenetic and viviparous reproduction throughout the year. Some species are a mix of holocyclic and anholocyclic clones. Within a species, the proportion of individuals that are holocyclic tends to be greater in colder regions, as the eggs resulting from sexual reproduction are very much more cold hardy than the active, viviparous forms which persist year round in anholocyclic clones.

Among the insects that are commonly associated with virus transmission, aphids are of particular interest in the Nordic region for a number of reasons. Aphids generally have a low developmental temperature threshold and a short generation time, so that when they continuously reproduce in a parthenogenetic manner, they achieve 18 generations a year in British conditions (Harrington 2002; Harrington et al. 2007). Yamamura and Kiritani (1998) suggested that aphids are among the insects best adapted to take advantage of a warming climate and could go through an extra five generations a year following a warming of 2°C. Others have suggested that besides increases in CO_2 concentration, differences in soil nitrogen content and population density also play a part for aphid abundance (Newman et al. 2003), but nevertheless, they are expected to increase in importance as pests in Sweden (Fågelfors et al. 2009).

Although temperature is a key factor governing insect life in general and that of aphids in particular, aphids are also affected by the environment through the host plants. Increases in concentrations of CO_2 and O_3 are of particular significance. Indeed, increases in CO_2 concentration stimulate plant growth but decrease the nutritional quality of plants for phytophagous insects (Lincoln et al. 1993). By contrast, ozone tends to inhibit plant growth by decreasing carbon fixation through negative effects on the rate of photosynthesis (Chappelka and Chevone 1992). The responses of aphids to high concentrations of CO_2, O_3, or both gases are highly variable. Depending on the aphid species, development and fertility rates may increase (Awmack et al. 1997; Mondor et al. 2005; Sudderth et al. 2005), decrease (Hughes and Bazzaz 2001), or remain unaffected by such atmospheric changes (Percy et al. 2002; Awmack et al. 2004). A single aphid clone may display different responses to high CO_2 content according to the host plant increase (Awmack et al. 1997; Mondor et al. 2005; Sudderth et al. 2005). Consequently, despite the many studies carried out on this subject, it is not possible to establish general rules or to predict whether all aphid populations will be affected by global warming (Newman et al. 2003; Pritchard et al. 2007).

Many of the 275 viruses transmitted by aphids cause diseases of major economic importance. Thus, the indirect damage that aphids cause through virus transmission often far exceeds their direct impact on crops. In vegetables and fruits, viruses are often associated with huge losses in quality with many unmarketable products. In field-grown vegetables, a synthesis by Tomlinson (1987) over 28 countries with temperate climate revealed that the five most economically important viruses are transmitted by aphids (Cucumber mosaic virus (CMV), Turnip mosaic virus (TuMV), Potato virus Y (PVY), Lettuce mosaic virus (LMV), and Papaya ringspot virus (PRSV)). The two most common viruses of potatoes, PVY and Potato leaf roll virus (PLRV), are transmitted by aphids and are of particular concern to seed potato producers. In India, Banana bunchy top virus (BBTV), Bean yellow mosaic virus (BYMV), Cardamom mosaic virus (CdMV), Chilli veinal mottle virus (ChiVMV), Citrus tristeza virus (CTV), Cucumber mosaic virus (CMV), Dasheen mosaic virus (DsMV), Papaya ringspot virus (PRSV), Potato virus Y (PVY), and Zucchini yellow mosaic virus (ZYMV) are of importance in horticultural crops, which also impacts on crop production under varied climatic conditions (Krishnareddy and Manasa 2012).

23.2.2 Impact on Whitefly and Whitefly-Transmitted Viruses

B. tabaci corresponds to a complex of genetic variants or haplotypes, usually referred to as biotypes (Gill and Brown 2010). Based on mitochondrial cytochrome oxidase subunit (COI) gene consensus sequences, a recent report has suggested that *B. tabaci* is a complex of at least 24 distinct cryptic species (Dinsdale et al. 2010). Although no morphological characteristics can be used to distinguish between *B. tabaci* populations, genetic and behavioral differences have been used for haplotype/biotype characterization. These include isoenzyme profiling, bar coding based on conserved genes like the mitochondrial COI gene, life history traits, host range and/or host preference, virus transmission competency, composition of endosymbionts, dispersal behavior, insecticide resistance, and discontinuous gene flow. Biological differences between *B. tabaci* biotypes can radically affect the emergence of a virus disease by causing differences in transmission efficiency, host range, or mating behavior (Navas-Castillo et al. 2011). Whiteflies can transmit plant viruses in a semi-persistent manner (e.g., criniviruses) or a persistent manner (e.g., begomoviruses). Interestingly, the persistent transmission of some begomoviruses involves a third partner. Thus, persistent transmission of TYLCV by *B. tabaci* depends on chaperonin GroEL homologs produced by endosymbiotic bacteria (Morin et al. 1999).

Over the past 20 years or so, begomoviruses have emerged as serious constraints to the cultivation of a variety of vegetable crops in various parts of the world but especially in the tropics and subtropics (Moriones and Navas-Castillo 2000; Rojas and Gilbertson 2008; Morales 2010). Some devastating begomoviruses have also moved to temperate regions, where they seriously reduce greenhouse crop production. The emergence of begomoviruses is associated with changes in crop cultivation, increased global movement of plants, and changes in cropping practices, such as the intensive use of insecticides. In particular, the emergence of begomoviruses as important pathogens over the past two decades is closely associated with the increased prevalence of the insect vector, the whitefly *Bemisia tabaci* (Wisler et al. 1998a). The spread of begomoviruses by *B. tabaci* has been facilitated by the introduction in many areas of the polyphagous B biotype of *B. tabaci*, which feeds on a wide range of plants and thus has a high probability of acquiring and transmitting a diversity of begomoviruses into potential new hosts. In the mid-1980s, for example, B biotype was introduced into the New World, where it often displaced the local A biotype, which is less polyphagous than B biotype (Morales 2010). As a result, begomoviruses have supplanted potyviruses as the group of plant viruses with the largest number of recognized species. *B. tabaci* has also been involved in the emergence of new diseases caused by other groups of viruses, such as criniviruses (Wisler et al. 1998a) or ipomoviruses (Adkins et al. 2010). *Trialeurodes vaporariorum*, another whitefly able to transmit some criniviruses, was long restricted to greenhouse crops but in some areas has become increasingly important as a pest in open-field vegetable production over the past 20 years (Wintermantel 2004).

Increased incidence of whitefly-transmitted viruses has been noticed in India in beans, cassava, chilli, cucurbits, okra, potato, and tomato. This may be due to occurrence of B and Q biotypes of whitefly population which rapidly multiply under changed climatic conditions. This also led to the breakdown of resistance to yellow vein mosaic virus of okra and severe incidence of begomoviruses on cucurbits throughout India, which were not known to be infected with begomoviruses. Recent surveys in vegetable crops have indicated the occurrence of new criniviruses in India such as cucurbits and tomato (Krishnareddy and Manasa 2012).

23.2.3 Impact on Thrips and Thrips-Transmitted Viruses

Thrips are insects belonging to the order Thysanoptera (Mound 2005). Some thrips can affect plants by direct feeding, which may leave visible signs of damage, such as leaf silvering (Palmer et al. 1989). A few of these thrips transmit plant viruses. Thrips-transmitted viruses can cause significant diseases of many crop plants, and their impact worldwide is immense (Mumford et al. 1996; Ullman et al. 1997). Tospoviruses belong to the sole phytovirus genus, *Tospovirus*, in the family *Bunyaviridae.* Tospoviruses are known to be exclusively transmitted by thrips belonging to the family Thripidae and subfamily Thripinae. Of the known 1,710 species of Thripidae, only 14 thrips species are currently reported to transmit tospoviruses. Thrips-transmitted tospoviruses cause severe yield losses to several economically important crops in the United States and worldwide. Global trade and associated movement of plant materials across borders have introduced tospoviruses and their vectors into newer areas (David et al. 2011).

Species in the *Thrips*, *Frankliniella*, *Scirtothrips*, *Microcephalothrips*, *Dictyothrips*, and *Ceratothripoides* genera have been shown to transmit plant viruses. Thrips transmit plant viruses in the Tospovirus, Ilarvirus, Carmovirus, Sobemovirus, and Machlomovirus genera (Jones 2005; Riley et al. 2011). Thrips lay eggs, which hatch to produce two larval instars that feed on plants. Larval instars are followed by two relatively inactive pupal instars that probably do not feed. In warm conditions, the life cycle usually takes about 20 days from egg to adult. Adults are readily dispersed. Thrips can transmit viruses as (1) a mechanical accident of feeding on leaves covered with virus-carrying pollen, (2) by transferring virus-carrying pollen by mechanical accident feeding, and (3) as the result of a more sophisticated relationship in which the virus is ingested and multiplies within the body of the insect. The third mechanism, which is restricted to viruses in the Tospovirus genus, has resulted in the most serious threat to world agriculture.

Thrips development is known to be dependent on temperature. Adult females can survive for 4–5 weeks at 30°C and oviposit 50 eggs (Reitz 2008). *Frankliniella occidentalis* requires a minimum of 194° days (minimum temperature 9.5°C) to complete a generation (Katayama 1997) but has been estimated to be as high as 254° days with a minimum temperature of 6.5°C (Lowry et al. 1992).

The few species of thrips that transmit tospoviruses, which are less than 0.2% of the total, are not closely related to each other (Mound 2001a, 2005). Only six species of Frankliniella, three species of Thrips, and one species each of Scirtothrips and Ceratothripoides are known to be vectors. Tospoviruses are transmitted by several species of thrips in a circulative and propagative manner (Mound 1996; Ullman et al. 1997; Whitfield et al. 2005). While there are more than 5,000 thrips species, so far only 10 are known vectors of tospoviruses, suggesting marked coevolution for transmission specificity between tospoviruses and these thrips vector species. Both larval and adult stages of thrips vectors can actively feed on virus-infected host plants, but only early larval instars can acquire the virus, and later instar larvae and adults can transmit the virus after a latent period (Wijkamp et al. 1996a; Ullman et al. 1997; Whitfield et al. 2005; Persley et al. 2006). Adult thrips can acquire tospoviruses, but they do not transmit them. This is presumably because of insufficient multiplication in the midgut, a lack of movement to salivary glands, and a lack of multiplication thereafter. These are prerequisite for *Tospovirus* transmission (Wijkamp et al. 1996b). In addition, tospoviruses are not transmitted transovarially (Wijkamp et al. 1996a). Thus, each new generation of thrips vectors must acquire the virus as larvae. There are distinct associations between thrips species and their ability to transmit specific tospoviruses (Jones 2005).

The transmission of ilarviruses by thrips is a different mechanism. It involves the physical movement of virus-carrying pollen from one plant to another and its introduction into the plant through feeding wounds. Thrips in the genera Frankliniella, Microcephalothrips, and Thrips have been implicated in the spread of Tobacco streak virus (TSV) (Kaiser et al. 1982; Sdoodee and Teakle 1987; Marchoux et al. 1999) and Prunus necrotic ringspot virus (PNRSV) (Greber et al. 1991) ilarviruses though more may be discovered. There has been one report of transmission of a carmovirus by thrips utilizing the same mechanism as for ilarviruses. *F. occidentalis* has been found to transmit Pelargonium flower break virus (PFBV) (Krczal et al. 1995), a carmovirus. One sobemovirus can also be transferred with pollen by thrips and plants infected during feeding. This virus can also be carried from one plant to another on the mouthparts of thrips. *T. tabaci* transmit Sowbane mosaic virus (SoMV) (Hardy and Teakle 1992), a sobemovirus and Maize chlorotic mottle virus (MCMV) (Ullman et al. 1992), a machlomovirus. One machlomovirus is also thought to be thrips transmitted, but the actual mechanism is not clear.

23.2.4 Impact on Leafhopper and Psyllids and Vector-Transmitted Phytoplasma

Phytoplasmas are phloem-limited plant pathogens that are spread by sap-sucking insect vectors belonging to the families Cicadellidae (leafhoppers) and Fulgoridae (plant hoppers) (Brcak 1979; Tsai 1979; Banttari and Zeyen 1979; Nielson 1979). Insects feed on phloem tissues, where they acquire phytoplasmas and transmit them from plant to plant. During their transmission cycle, phytoplasmas cross the insect midgut lining, circulate and reproduce in the hemolymph, and invade and multiply in insect tissues including salivary glands, where phytoplasmas are integrated into saliva and injected into the plant phloem during feeding (Lherminier et al. 1990; Lefol et al. 1994; Nakashima and Hayashi 1995; Bertamini et al. 2002). Phytoplasmas may overwinter in infected vectors, as well as in perennial plants that serve as reservoirs for phytoplasmas.

Additionally, phytoplasmas can be spread by vegetative propagation through cuttings, storage tubers, rhizomes, or bulbs (Lee and Davis 1992). Phytoplasmas that cause many ornamental and fruit tree diseases are spread by vegetative propagation and grafting.

Weintraub and Beanland (2006) have reviewed the vectors of phytoplasmas. The single most successful order of insect phytoplasma vectors is the Hemiptera, which includes the Sternorrhyncha and Auchenorrhyncha. They point out that this group collectively possesses several characteristics that make its members efficient vectors of phytoplasmas: (a) they are hemimetabolous; thus, nymphs and adults feed similarly and are in the same physical location, and often both young ones and adults can transmit phytoplasmas; (b) feed specifically and selectively on certain plant tissues, which makes them efficient vectors of pathogens residing in those tissues; (c) have a propagative and persistent relationship with phytoplasmas; and (d) have obligate symbiotic prokaryotes that are passed to the offspring by transovarial transmission, the same mechanisms that allow the transovarial transmission of phytoplasmas. Climate change is predicted to have a progressively negative effect on the yield of food crops. Climatic variability can affect not only the pathogen but also plant host and insect vector, as well as the interactions between or among these organisms (Luck et al. 2011). Vector–host plant interactions play an important role in limiting or expanding phytoplasma spreading. Broadly polyphagous vectors have the potential to inoculate a wider range of plant species, depending on the susceptibility of each host plant. Several studies have shown that insects that normally do not feed on certain plant species can acquire and transmit phytoplasma to those plants under laboratory conditions. Hence, in many cases, the plant host range of a vector, rather than lack of phytoplasma-specific cell membrane receptors, will limit the spread of phytoplasma by that species (Weintraub 2007; Nault and Ammar 1989).

Bois noir in grapevine and potato stolbur are caused by phytoplasmas of the stolbur (16Sr-XII-A) group and transmitted by the plant hopper *Hyalesthes obsoletus*, a southern European, xerothermic species. The fact that stolbur phytoplasma and its vector were present for a long time at viticultural sites but occurred just recently in potatoes appears contradictory. However, potatoes are grown in areas where ambient temperatures were not sufficient for the vector to complete its life cycle. Changing climatic conditions could have allowed *H. obsoletus* not only to spread to new viticultural sites but also to potato-growing areas with a rather mild climate. Since early maturing varieties are grown there, stolbur symptoms might become visible only in years when high spring temperatures lead to an exceptionally early flight of *H. obsoletus* and an inoculation of the potato plants ahead of the normal time in July (Lindner et al. 2007).

23.2.5 Changes in Vector Population Dynamics

The population dynamics is the aspect of population ecology dealing with factors affecting changes in population densities. The seasonal effects of weather and ongoing changes in climatic conditions will directly lead to modifications in dispersal and development of insect vector species. The changes in surrounding temperature regimes certainly involve alterations in development rates, voltinism, and survival of insect vectors and subsequently act upon size, density, and genetic composition of populations, as well as on the extent of host plant exploitation (Bale et al. 2002). The change in the environment affects the pest population dynamics in two ways either directly or indirectly by altering the host physiology. Host availability and the probability of vector outbreaks are further determined by the incidence and character of abiotic disturbances. The developmental success of insect herbivores also indirectly depends on climate, as environmental parameters impact on plant physiology. Insects and plants are exposed to complex interactions among changes in temperature, precipitation conditions, and increased levels of CO_2 and variations in nutrient availability (Karuppaiah and Sujayanad 2012).

Changes in vector populations are frequently the result of human activities such as the introduction of exotic insects into new areas or the intensive use of insecticides. Vector insect populations may also be altered by climate change (Canto et al. 2009; Jones 2009). There are numerous examples of human-mediated introduction of different biotypes of *B. tabaci*. Human activity, for example, was responsible for the spread of the B biotype from its presumed origin in the Mediterranean–Asia Minor region to rest of the world. As noted earlier, the introduction of the B biotype has often led to the displacement of indigenous *B. tabaci* populations (Brown et al. 1995).

The importance of changes in biotype composition of *B. tabaci* populations lies in the biological differences between biotypes that are relevant to the emergence of virus diseases. These biological differences include differences in virus transmission efficiency, plant host range, mating behavior, and rate of population increase. It has been well documented that the B biotype of *B. tabaci* has larger populations and a broader host range than the A biotype. This probably explains why, in many regions of the New World, the exotic B biotype has displaced the native A biotype (Morales 2010). Mating behavior also differs among *B. tabaci* biotypes. Caged experiments and behavioral observations have shown that the males of the invading B biotype copulate more frequently than native males in China and Australia. This behavior of B biotype males interferes with mating by native males and increases the production of female progeny of the B biotype. Such asymmetric mating interactions may help explain the capacity of the B biotype to invade and displace indigenous populations (Liu et al. 2007).

Aphids show a considerable variation in their life cycle traits and even within species variation can be very high. Some species, termed holocyclic, respond to the oncoming winter with a sexual phase, often placing eggs on woody plants. Anholocyclic aphids, on the other hand, do not go through the sexual phase and continue with parthenogenetic and viviparous reproduction throughout the year. Some species are a mix of holocyclic and anholocyclic clones. Within a species, the proportion of individuals that are holocyclic tends to be greater in colder regions, as the eggs resulting from sexual reproduction are very much more cold hardy than the active, viviparous forms which persist year round in anholocyclic clones. Research from Poland suggests that there has been a radical reduction in the proportion of holocyclic clones of some aphid species in recent years (Ruszkowska et al. 2010; Dedryver et al. 2010). If this trend is reflected in Sweden, then aphids may soon be reproducing asexually all year round. This biological change may take place simultaneously with human-mediated changes in the availability of host plants. Autumn sowing, for example, will become more common, and autumn sown cereals have doubled in acreage in Sweden from 1981 to 2009 (Svensson 2010). This leads to the risk of a so-called green bridge, when winter crops may emerge sufficiently early to receive insects migrating from maturing crops, which can be especially important for vectors such as aphids and the transmission of virus. Warmer autumns and winters will increase the risk for insect transmission of viruses into winter crops, such as winter wheat, winter barley, and winter oilseed rape. They are now sown when the number of active insect vectors has decreased significantly.

Wheat dwarf virus (WDV) is transmitted in a persistent manner by the leafhopper *Psammotettix alienus*. At the beginning of the last century, a disease presumed to be caused by WDV severely affected wheat in central Sweden (Lindsten and Lindsten 1999). It has since then periodically damaged winter wheat in the central parts of Sweden. The periodic reappearance of the disease has been associated with changes in agricultural practices (Lindsten and Lindsten 1999; Lindblad and Waern 2002). The host range of WDV includes many common grasses, and a recent study has shown that grasses growing in vicinity to WDV-affected wheat fields are infected (Ramsell et al. 2008). These grasses may act as a long-term reservoir for the virus. The leafhoppers acquire WDV from infected volunteer plants or grasses and then transmit the virus into winter wheat at the beginning of the autumn.

They overwinter as eggs, and in spring, wingless nymphs transmit WDV from the infected wheat plants in the field (Lindblad and Sigvald 2004). A study in Sweden showed that the catches in autumn of adult *P. alienus* in fields of winter wheat increased with higher temperatures. During weeks with an average maximum temperature below 10°C, only few leafhoppers were caught in yellow water traps, but during weeks above 10°C, the numbers increased with temperature, with high insect numbers noted above 15°C (Lindblad and Arenö 2002). When the crop is not infected in the autumn, the damage from WDV will be very limited. Mature wheat plant shows resistance against WDV with at growth stage DC31, when the first node is detectable (Lindblad and Sigvald 2004). Therefore, when the winged adult form of *P. alienus* is ready to transmit WDV between wheat fields, the wheat has already reached the resistant stage. In continental and southern Europe, winter barley is affected by the barley strain of WDV. This strain is distinct from the wheat strain infecting wheat in Sweden and other parts of Europe and Asia (Ramsell et al. 2009). There is now a risk that the barley strain of WDV may also appear in Sweden. Similar problems with autumn infection of winter crops are expected with Barley yellow dwarf virus-PAV (BYDV-PAV) and BYDV-MAV, which are persistently transmitted by different aphid species. With increased temperatures in temperate regions, disease epidemics caused by aphid-borne viruses are likely to be more severe (Jones 2009). In Germany, a clear relation was recently found between the number of infection days in autumn and BYDV attack in winter barley fields (Habekuß et al. 2009).

23.3 Climate Change and Plant Virus Diseases

The dynamics of plant virus epidemics and the losses they cause are likely to be influenced greatly by (1) the direct consequences of climate change such as altered rainfall patterns, increased temperature, and greater wind speeds and (2) indirectly by factors such as regional alterations in the areas cropped and the ranges of crops grown, and changes in the distribution, abundance, and activity of vectors. Such influences are likely to alter the geographic ranges and relative abundance of viruses, their rates of spread, the effectiveness of host resistances to virus infection, the physiology of host–virus interactions, the rate of virus evolution and host adaptation, and the effectiveness of control measures. However, the magnitude of such effects on the frequency and duration of virus epidemics will vary depending on the pathosystem and geographical region concerned making it difficult to generalize (Norse and Gommes 2003; Garrett et al. 2006; Krishnareddy et al. 2010).

23.3.1 Geographical Distribution of Host, Vector, and Virus

New virus disease complexes may arise, and some diseases may cease to be economically important if warming causes a poleward shift of agroclimatic zones and host plants migrate into new regions. Viruses and vectors would follow the migrating hosts and may infect remnant vegetation of natural plant communities not previously exposed to the often more aggressive strains from agricultural crops (Coakley et al. 1999). The mechanism of pathogen dispersal, suitability of the environment for dispersal, survival between seasons, and any change in host physiology and ecology in the new environment will largely determine how quickly pathogens become established in a new region. In India, Tobacco streak virus occurred after severe drought during 1997 on sunflower crop in Karnataka. Soon this virus shifted to groundnut in Andhra Pradesh, causing severe yield loss during 2002. Later this virus started appearing epidemic on vegetable crops causing epidemic in gherkin and okra in Karnataka (Krishnareddy et al. 2003a, b).

If the frost line moves north in the Northern Hemisphere, higher winter temperatures could be accompanied by increased survival of insects. For virus–vector aphids, this could lead to higher incidence of virus diseases, especially in those regions where the timing of virus arrival is linked to winter survival and spring flight of aphids. Barley yellow dwarf potyvirus (BYDV) is an example of a virus that causes more severe disease following mild winters. Since BYDV is exclusively transmitted by aphids, increased survival of pathogen reservoirs could greatly increase the economic losses caused by infection. Similar increases in viruses of potato and sugar beet have also been observed following warmer winters (Carter and Harrington 1991). Polák (2009) monitored climate change impacts on plant pathogen distribution such as *Zucchini yellow mosaic virus* (ZYMV), quarantine *Plum pox virus* (PPV), and phytoplasma European stone fruit yellows (ESFY). ZYMV has spread from Northern Italy across Austria up to Central Moravia and Bohemia. PPV has been continuously spreading from the lowlands of Central Bohemia and Moravia up to plains. Later, from the 1960s and 1970s of the last century, due to climate warming and human activities, the virus quickly spread to uplands, foothills, and mountains of the Czech Republic. Phytoplasma ESFY was spreading in a manner similar to ZYMV in the 1980s of the twentieth century from Northern Italy and currently is affecting mainly apricot and peach trees in Southern Moravia. The range of plant species that can be infected by a given phytoplasma in nature is determined by the number of insect vector species capable of transmitting the phytoplasma and by the feeding behaviors of these vectors. Mixed phytoplasma infections in a single plant are found in nature and can be experimentally generated (Lee et al. 1995; Alma et al. 1996; Bianco et al. 1993; Marcone et al. 1995). Co-infection also provides opportunities for the exchange of genetic information which may also contribute to the evolution of new strains.

23.3.2 Impact on Emergence of Viruses and Increase in Virus Epidemics

Small changes in average temperatures can suffice to bring about substantial shifts in the distribution and abundance of arthropod vectors of plant viruses (Anderson et al. 2004). Aphid vectors, in particular, are expected to react strongly to climatic changes because of their short generation time and low developmental threshold temperatures (Harrington et al. 2007). Increases in their numbers will lead inevitably to a higher risk of damaging epidemics of aphid-borne viruses. The spread of Papaya ringspot virus (PRSV) throughout the country recently, which was earlier restricted to the few places in northern India, is the best example. *A. gossypii* is one of the predominant vectors, followed by *A. craccivora* and *M. persicae* (Kalleshwaraswamy and Krishnakumar 2008). Peak aphid population of *A. gossypii* during March and April was a primary factor for a high incidence of new PRSV infections during April to May. The seasonal dynamics of *A. gossypii* was linked to the large-scale cultivation of cucurbitaceous vegetables from November to late March in south India (Kalleshwaraswamy et al. 2007).

With aphid vectors, ability to overwinter in temperate climates is enhanced by shorter cold spells and fewer days with frosts, allowing them to increase the duration of their activity annually and expand their geographical ranges (Norse and Gommes 2003). Harrington et al. (1995) suggested that, particularly for *Myzus persicae,* an increase of 1°C in the mean winter (January–February) temperature will advance the timing of spring aphid migration by 2 weeks. Such an advance taking place comes from the UK (Harrington 2002). In general, the date of first recording of aphid species in Europe is expected to advance by an average of 8 days over the next 50 years, the actual rate of advance varying with location and aphid species (Harrington et al. 2007). In temperate zones, a warming of 2°C is anticipated to give rise to an extra five generations of aphids/year (Yamamura and Kiritani 1998). In such zones, epidemics of diseases caused by aphid-borne viruses are likely to be more severe in the future as a result of increased aphid activity. These diseases include “yellow dwarf” in cereals, “virus yellows” in sugar beet, and “leaf roll” in potatoes (Harrington 2003; Qi et al. 2005). The opposite scenario applies in regions with Mediterranean-type climates and rain-fed, winter cropping, as the ability of aphid vectors to oversummer is likely to be decreased by the hotter, dryer summer conditions, for example, with the cereal aphid vectors of BYDV in parts of Southwest Australia (Hawkes and Jones 2005; Thackray et al. 2009). Although temperature and rainfall are the principal factors that influence aphid numbers, others connected with climate change such as elevated carbon dioxide also have the potential to do so. Taking these into account, model predictions for the effect of climate change on abundance and distribution of cereal aphids in the UK and Canada gave conflicting results, with populations declining in summer in some regions but increasing in others (Newman 2004, 2005, 2006). Watermelon mosaic virus (WMV, genus Potyvirus, family Potyviridae) was reported for the first time in France in 1974, and it is now the most prevalent virus in cucurbit crops. In 2000, new strains referred as 'emerging' (EM) strains were detected in South-eastern France. EM strains are generally more severe and phylogenetically distinct from those previously reported in this country and referred as 'classic' (CL) strains. Since 2000, EM strains have been progressively replacing CL strains in several areas where they co-exist (Desbiez et al. 2009). In order to explain this rapid shift in virus populations, the biological properties of a set of 17 CL and EM WMV isolates were compared. No major differences were observed when comparing a limited host range including 48 different plant species or cultivars. Only two species were differential; Chenopodium quinoa was systemically infected by CL and not by EM isolates whereas Ranunculus sardous was systemically infected by EM and not by CL isolates. A considerable variability was observed in aphid transmission efficiencies but this could not be correlated to the CL or EM types. Two subsets of five isolates of each group were used to compare aphid transmission efficiencies from single and double (CL–EM) infections using six different cucurbit and non-cucurbit hosts. EM isolates were generally better transmitted from mixed CL–EM infections than CL isolates and CL transmission rates were significantly lower from double than from single infections (Lecoq et al. 2011).

Temperature and rainfall are two of the principal factors affecting the important vector whitefly species, *B. tabaci*, with its population being diminished drastically by low temperatures and heavy and persistent rainfall. To flourish, it requires a dry season with duration of 4 months of rainfall less than 80 mm a month and a mean monthly temperature of at least 21°C in the hottest month of the year (Morales and Jones 2004). Such conditions are likely to occur over increasingly wide areas in middle latitude regions as global warming progresses. As more regions of Asia, Australia, Latin America, and Africa develop longer dry seasons, the likelihood of damaging epidemics of viruses transmitted by *B. tabaci*, such as begomoviruses on many important crops, will occur more frequently (Morales and Jones 2004).

The high incidence of new *Tospovirus* spp. in tropical Asian regions suggests a "hot spot" of viral genetic diversity in reservoir host variants from where they are transmitted to commercial crops through increasing vector populations (Rojas and Gilbertson 2008; Gent et al. 2006). The tospoviruses have been known in India since 1968 (Reddy et al. 1968) and have become a major problem for several field and horticultural crops. Because of varied climatic conditions, crop diversity, and both intensive and extensive cultivation of agri-horticultural crops, India has a variety of tospovirus isolates. There have been at least more than five tospoviruses reported on different crops from India (Prasada Rao et al. 1980; Reddy et al. 1992; Singh and Krishnareddy 1996; jain et al. 1998; Krishnareddy et al. 2008; Kunkalikar et al. 2010, 2011). The results also revealed an expanded host range of GBNV and WBNV that may facilitate their natural mixed infections in tomatoes and watermelons (Kunkalikar et al. 2011).

23.3.3 Impact on Incidence and Spread of Viruses

Although most of the information available on the influence of whitefly populations on virus emergence comes from studies with *B. tabaci* and begomoviruses, emerging diseases caused by criniviruses may also be affected by shifts in whitefly populations (Wintermantel 2010). Unlike begomoviruses, criniviruses can be transmitted by species of both *Bemisia* and *Trialeurodes*. *Tomato chlorosis virus* (ToCV), for example, is transmitted by *T. vaporariorum*, *T. abutiloneus*, and by the A, B, and Q biotypes and perhaps other biotypes of *B. tabaci* (Wisler et al. 1998b; Navas-Castillo et al. 2000). Most criniviruses, however, are transmitted by only one whitefly species. Therefore, the prevalence of different whitefly species can greatly affect the incidence of crinivirus outbreaks. A clear example has been reported from southeastern Spain, where melons (*Cucumis melo*) and cucumbers (*Cucumis sativus*) have been seriously affected since the late 1970s by yellowing diseases transmitted by whiteflies. Two criniviruses have been associated with these diseases: *Beet pseudo-yellow virus* (BPYV), which is transmitted by *T. vaporariorum*, and *Cucurbit yellow stunting disorder virus* (CYSDV), which is transmitted by *B. tabaci*. CYSDV-associated yellowing emerged in Spain in the early 1990s, coinciding with the displacement of *T. vaporariorum* by *B. tabaci* as the prevalent whitefly species in the greenhouses of this area. As a consequence of this, CYSDV displaced BPYV, present in the area since the late 1970s.

Climate change models predict an increase in global average temperature that could affect both host plants and insect vector populations. In particular, changes in a vector's overwintering biology, geographical distribution, density, migration potential, or phenology could affect virus survival, movement, and distribution and therefore could affect virus epidemics and the emergence of virus diseases in new areas or new crops (Garrett et al. 2006; Canto et al. 2009; Hanssen et al. 2010). The distribution of *B. tabaci* and other whitefly species depends largely on climatic conditions, in that high temperatures and low rainfall and humidity favor its reproduction (Morales and Jones 2004). Such conditions are likely to occur over increasing areas in middle latitudes if global warming continues. Thus, emergence of viruses transmitted by this insect can be expected in new areas following its expansion. Direct effects on plant health of climate warming, increased pollutants and CO_2 concentrations (Kliejunas et al. 2008; McElrone et al. 2010; Davies et al. 2011; Eastburn et al. 2011) will be accompanied by the easier introduction of exotic invasive species (Chakraborty et al. 2000; Lonsdale and Gibbs 2002; Ganley et al. 2011; Chytrý et al. 2012). Introductions of novel plant pathogens have already occurred in many regions (Brown and Hovmøller 2002; Dehnen-Schmutz et al. 2010; Stenlid et al. 2011), but climate changes are likely to often facilitate their further establishment and spread (Anderson et al. 2004; Shaw 2009; Hannukkala 2011). There is a consensus that prediction and management of climate change effects on plant health are complicated by interactions between globalization, shifts in climate, pollution and increasing numbers of invasive plants, pests and pathogens (Mistretta 2002; Desprez Loustau et al. 2007; Danon et al. 2011).

23.3.4 Impact on Phytoplasma Distribution and Multiplication

The increasing threat of phytoplasma diseases worldwide comes both from emerging diseases in Africa, Latin America, and the Caribbean mainly in sugarcane, corn, coconuts, papaya, and vegetables and from devastating epidemics in the rest of the world in grapevines, citrus, forest trees, oilseed crops, alfalfa, stone, and pome fruits. In both cases, diseases have the potential to spread to other crop species throughout the world and/or impact on global trade. There are concerns that climate changes resulting from global warming may facilitate the spread of these phytoplasma diseases to new areas and to additional crops, particularly if the vectors become more widespread and able to survive during warmer winters. Phytoplasmas usually do not kill the host plant in short time; however, unusually cold conditions kill infected plants, while under tropical conditions, asymptomatic plant presence is frequent with severe epidemiological consequences (McCoy et al. 1989).

The geographical distribution and impact of phytoplasma diseases depend on the host range of the phytoplasma as well as the feeding behavior of the insect vector. Some have a broad range of plant hosts and polyphagous vectors and therefore have a wide distribution. This is the case for "*Candidatus (Ca.)* Phytoplasma asteris," which has been reported in many crops worldwide. But many phytoplasmas have restricted host ranges and oligophagous or monophagous insect vectors, which restrict their geographical distribution. To date, no studies have linked changes of phytoplasma disease impact or geographical distribution to changes in climatic conditions. Many biological parameters influencing phytoplasma epidemiology can theoretically be affected by climate change. As a result of global warming, local increase in mean temperature can act at the level of insect vector population dynamics, biology, and fitness, but also at the level of the interaction between the phytoplasma and its two hosts: the plant and the insect vector. Events such as a storm or change in wind conditions can affect insect vector dispersal (Lee et al. 2000).

The predicted increase of mean temperature over the planet will increase the phytoplasma multiplication rate early in the season, when temperature is suboptimal. For example, in a temperate climate, it may be surmised that an increase in mean temperature during spring will result in a higher multiplication of phytoplasmas in plants and insects. On the infected plant side, it will result in an earlier development of symptoms, which might also be more severe, as a higher number of phytoplasmas in the plant may result in an increased disease severity. This reduction of the incubation period in the plant should also reduce the acquisition access period: the time necessary for acquisition of the pathogen by the insect vector feeding on the infected plant. Phytoplasmas will also multiply faster in the insect vector, thus decreasing the latency period necessary for the insect colonization by the phytoplasma (Foissac and Wilson 2010). Galetto et al. (2011) studied multiplication patterns of two phytoplasmas, "chrysanthemum yellows" and "flavescence dorée," in insect vectors and plant hosts under different climatic conditions. Phytoplasma multiplication was faster under cooler conditions in insects (P1, 18–22°C; CO_2 400 ppm) and under warmer conditions in plants (P2, 22–26°C; CO_2 800 ppm). An influence of temperature and CO_2 concentrations was observed for chrysanthemum yellows latency in the vector only. Results suggest that T and CO_2 influence on phytoplasma multiplication is host dependent.

Conversely, the detrimental influence of phytoplasma infection on insect fitness can reduce the opportunities of phytoplasma disease propagation. It is known that the maize bushy stunt phytoplasma (group 16SrI) and the flavescence doree phytoplasma (group 16SrV) reduce the lifespan of their respective insect vectors, *Dalbulus longulus* DeLong and S. *titanus* (Nault et al. 1984; Bressan et al. 2005). Interestingly, the pathogenicity of the Western-X phytoplasma (group 16SrIII) to its vector *Paraphlepsius irroratus* (Say) is temperature dependent (Garcia-Salazar et al. 1991). Phytoplasmas have a broad host plant range, which depends on the plant feeding range of their insect vectors. With more than 100 isolates, the aster yellows phytoplasma (AYP) subclade Candidatus (Ca.) Phytoplasma asteris previously known as 16srI clade phytoplasmas comprises the largest among the Ca. phytoplasma subclades (Marcone et al. 2000; Seemuller et al. 1998). Aster yellows phytoplasma are vectored by at least 30, often polyphagous, insect species and, as a consequence, are capable of infecting more than 80 plant species (Firrao et al. 2007), including many weeds that surround crop fields (Marcone et al. 2000). For example, aster yellows phytoplasma strain Witches' Broom (AY-WB) can be transmitted by the polyphagous *Macrosteles quadrilineatus* (Forbes) to China aster and lettuce (Zhang et al. 2004). The broad plant and insect host ranges make phytoplasma outbreaks unpredictable. Further, because of the long incubation periods of phytoplasmas in plants and insects, outbreaks are often detected too late, that is, close to harvesting of the crops and after dispersion of the phytoplasmas by the insect vectors.

23.3.5 Impact on Host Resistance

In addition to the impacts on vectors, climate change alters the frequency and duration of virus epidemics when increased temperature changes the rates of virus multiplication, modifies host resistance, and changes the physiology of host–virus interactions. Viruses have different temperature optima for multiplication. Some are adapted to warmer regions and others to temperate regions. The distributions of the former are likely to increase as the world warms, and the ranges of crops currently restricted from being grown in cooler regions by temperature expand. Temperature-sensitive resistance genes which are currently effective (Fraser 1986, 1990) may become ineffective when virus epidemics occur in formerly resistant cultivars of crops grown under warmer conditions than previously. In semiarid and arid mid-latitude regions, increased drought stress may enhance crop vulnerability to virus infection by changing the physiology of host–virus interactions, thereby increasing the occurrence of damaging virus epidemics, for example, of begomoviruses. Moreover, drought stress and disease stress may have additive effects resulting in greater damage, as with *Beet yellows virus* and *Maize dwarf mosaic virus* (Olson et al. 1990; Clover et al. 1999).

Elevated carbon dioxide and ozone also have the potential to influence the effectiveness of host resistance and suppress pathogen-induced resistance (Garrett et al. 2006) and so alter the occurrence of virus epidemics. Warmer growing conditions will alter selection pressures on viruses and modify virus evolution rates, thereby influencing the magnitude of virus epidemics. Changes in the ranges and geographical distributions of crops and geographic expansion of virus and vector distribution resulting from increasing temperatures and altered rainfall patterns will inevitably increase the occurrence of “new encounters” between viral pathogens, their vectors, and host plants. This process of bringing more viruses into contact with more potential hosts will provide new opportunities for virus evolution and host species “jumps,” and further increases the rate of invasion of indigenous flora by introduced viruses and of introduced plants by indigenous viruses emerging from native plants to infect them (Anderson et al. 2004; Garrett et al. 2006). Conversely, in some situations, climate change may diminish the encounter rate between virus and host by changing the ranges of both so that they coincide less, for example, in middle latitude arid and semiarid regions by decreasing the overall amount of land in use for cropping or diminishing the fragmentation of remnant native vegetation.

Elevated ozone altered gene expression in soybean and induced a nonspecific defense response. Although the host defense response was not induced specifically to stop SMV infection but to cope with the environmental changes, it retarded the replication and spread of the host-dependent pathogen temporarily. The induced nonspecific defense has multiple components. Transcriptional increases of PR genes and ethylene, salicylic acid, and jasmonic acid signaling genes contributed to the defense response to a certain degree. The increase in flavonoid biosynthesis genes and the increase in several flavonoids indicated that flavonoid biosynthesis was one of the major players in the nonspecific defense response (Bilgin et al. 2008).

23.3.6 Impact on Host–Pathogen Interaction

Plant virus diseases severely constrain agricultural production worldwide (Van Den Bosch, et al. 2006), but the roles played by pathogens in determining an ecosystem response to elevated CO_2 have rarely been examined (Malmstrom and Field 1997; Malmstrom et al. 2011; Lake and Wade 2009). Elevated CO_2 levels directly impact plant physiology and result in an increase in the photosynthetic rate, which alters the growth and aboveground biomass (Agrell et al. 2000; Hartley et al. 2000). On the other hand, Malmstrom and Field (1997) found that the biomass of BYDV-infected barley decreases by 50–60% compared with healthy barley under atmosphere CO_2 levels, while the biomass of infected barley decreases by 39–40% compared with healthy plants under elevated CO_2. Generally speaking, few studies on pot-grown plants have discovered an insignificant growth response to elevated CO_2 (Sindelarova et al. 2005).

Ye et al. (2010) reported that elevated CO_2 increased plant aboveground biomass but did not significantly influence TNCs or nitrogen content, while PVYN infection had adverse effects on biomass, markedly affected the later two indices, but no interactive effects between elevated CO_2 and PVYN infection on these three indices were detected. As single factor, elevated CO_2 or PVYN infection reduced chlorophyll content, while elevated CO_2 increased the soluble protein content; interaction between two factors was observed on free amino acid and nicotine content. Variations in peroxides activity revealed that CO_2 influenced infected plant primary production by reducing virus resistance cost. Results suggested that plants grown under elevated CO_2 have alleviated damage of the virus infection or delayed the viral spread to some extent (Roos et al. 2011).

The transmission efficiency of many vector-borne plant viruses has been shown to be affected by temperature (Lowles et al. 1996; Sylvester 1980; Smyrnioudis et al. 2001). Temperature has also been demonstrated to have an impact on Banana bunchy top virus (BBTV) symptom development (Anhalt and Almeida 2008; Wu and Su 1990), spread (Allen 1978), transmission efficiency (Wu and Su 1990), and on vector biology (Anhalt and Almeida 2008; Smith et al. 1998). Wu and Su (1990) compared BBTV acquisition efficiency at 16°C, 20°C, and 27°C using groups of aphids for transmission experiments, demonstrating that temperature affected efficiency, with no transmission at 16°C and maximum efficiency at 27°C.

2 3.4 Conclusions

The world is undergoing a period of accelerated climate change accompanied by rapid expansion in human activity. Both of these factors are impacting plants, vectors, phytoplasma, and viruses, causing increased instability within virus–plant pathosystems. This has major implications on effective control of viral epidemics that diminish food production, especially those associated with virus emergence. It also makes this an exciting opportunity to study the changing dynamics of viral epidemiology, ecology and evolution in different regions, and their implications. This is especially so when new encounter scenarios render once reliable control measures less effective, or even entirely ineffective, in the future. A crucial component of such studies involves understanding viruses within wild plant populations and cultivated plants at natural and manmade ecosystem interface. This can provide critical information not only on the potential threats posed to cultivated species and biodiversity but also on virus evolution in response to rapidly changing conditions (Jones 2009).

Invasive viruses, vectors, and vector biotypes are increasing the frequency of new encounters. The other biological changes involved introduction of new, more efficient virus–vector species and more efficient virus–vector biotypes or variants of existing vector species, and circumvention of host defenses in introduced crops. At the molecular level, the genome alterations most likely to occur in different emerging viruses are those caused by recombination, pseudo-recombination, reassortment, and modular evolution. Alterations will also arise by selection from existing variants within virus populations, new mutations, synergism, genetic drift, population bottlenecks and "founder effects," presence of satellite viruses and nucleic acids, or genome integration (Anderson et al. 2004; Fargette et al. 2006; Jeger et al. 2004, 2006, 2011; Morales 2006; Seal et al. 2006a, b; Gibbs et al. 2008; Sacristan and Garcia-Arenal 2008).

The current rapid expansion in human activity includes adopting more intensive, extensive, and diverse agricultural practices; more widespread cultivation in monocultures; greater loss of genetic diversity; increased fragmentation and disturbance of indigenous vegetation; and misuse and overuse of chemical control measures, irrigation, and protected cropping. All of these provide conditions that favor emergence of viruses and development of damaging epidemics at the interface. It also includes the effects of continually expanding volume and greater rapidity of international trade in plants and plant products, combined with expanding travel by modern transport systems for tourism and business purposes, in moving plants away from their centers of diversity and dispersing previously localized weeds, viruses, and vectors widely. The spatial and temporal shifts in climate that will occur because of changes in temperature, rainfall, and wind patterns will cause regional alterations in the ranges of introduced crops grown and areas cropped, occurrence of introduced weed species, and the distribution, abundance, and activity of vectors. New encounter rates will increase as crops and weeds newly introduced to a region intermingle with the local native vegetation for the first time. The geographical ranges of vectors within continents will change, bringing them into first contact with indigenous viruses, and newly introduced weeds or crop plants that boost virus inoculum levels or vector populations will alter epidemic dynamics (Anderson et al. 2004; Morales and Jones 2004; Garrett et al. 2006; Harrington et al. 2007).

A less predictable climate will cause uncertainty in decision making over the timing of control measures (Garrett et al. 2006). Control measures likely to be less reliable to suppress future virus epidemics include manipulation of sowing date; timing of sprays with oils, repellents, or pesticides; adjusting harvesting times; and planting upwind. Crops grown where the climate is too warm or under drought stress may tend to be physiologically weak to withstand infection. Including nonselective control methods will be particularly important when attempting to tackle emergence of unknown or little understood viruses. In such instances, "interim" IDM tactics that use all available "generic" information on related pathosystems and situations need to be deployed.

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24

Pest Dynamics and Potential Emergence of New Biotypes Under Climate Change Scenario in Horticultural Crops

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Abstract

Insect pests are one of the major components of agricultural biodiversity, and like any other organisms, they are also vulnerable to climate change. Change is perceived to affect both directly and indirectly through their host plants. Insects, being cold-blooded, are more sensitive to climate variations. Increased temperature and CO_2 levels have potential to alter their life cycle, population distributions, virulence, susceptibility to insecticides, and phenological synchrony with host plants which in turn will have profound effects on crop productivity. In attempt to adapt to emerging scenarios, there is a possibility of development of new biotypes which would throw new challenges in pest management. Biotypes of *Bemisia tabaci* are taken as a case study to discuss these implications. Another angle of the potential impact of climate change on insect pests is through their natural enemies. Climate change-induced responses of insects may be either beneficial or harmful, depending upon the nature and habitat of the species. Getting to know the potential responses of insect populations to climate change makes it possible to evaluate the pest management alternatives as well as to formulate our future management policies.

24.1 Introduction

The main causes of climate change are natural changes in the components of earth's climate system and their interactions referred to as "internal forcing." The external forcing mechanisms include orbital variations, solar output, volcanism, and human influence. The Intergovernmental Panel on Climate Change (IPCC) reports an approximate temperature increase ranging from 1.1°C to 6.4°C by the end of this century. It took nearly 100 years to appreciate Malthusian theory, and the same may be true of climate change. In addition to rise in seawater levels inundating low-lying regions of the world, global warming impacts tropical, subtropical, and temperate parts of the world differentially. It is predicted that generally erratic rainfall followed by prolonged dry spell leads to spread of communicable

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vector-prone disease such as malaria and dengue, affecting human health. While a lot is talked on the effects of climate change on human health, less is said of plant health on which depends the existence of all living things on this earth. Horticultural crops are also sensitive and appear less hardy to withstand the vagaries of climate change. Compared to field crops, the number of pests and diseases is more on horticultural crops, and they can impact the nutritional security of our population especially the poor under the influence of climate change. Increased ambient temperatures frequently have direct consequences for metabolic rates, activity patterns, and developmental rates. Consequently, in many insect species, both an earlier beginning and prolongation of seasonal duration occurred parallel with global warming. However, from an ecological and evolutionary perspective, the number of generations (voltinism) and investment into each generation may be even more important than seasonality since an additional generation per unit time may accelerate population growth or adaptation. Food security of millions of people in the third world has faced a growing number of challenges in recent years including risks associated with emergent agricultural pests.

24.2 Insects and Changing Climate

Insects constitute one of the major components of agricultural biodiversity and are thought to mainly have negative impact on agriculture, as pests of crop plants, though their positive role as biocontrol agents and pollinators is of equal economic importance. Any change in the population dynamics and distribution pattern of insects will have a significant impact on crop productivity. Climate change has potential to bring about pronounced shifts in the insect behavior, their susceptibility to insecticides, and phenological synchrony with host plants. As global biodiversity is decreasing rapidly, species are introduced by humans into environments where they did not previously exist. This has induced an interest in the mechanisms underlying species arrangement within communities and the role of resident diversity to resist the establishment of exotic species. Though it is not a general rule, there is an increasing evidence that invading species may have substantial effects on the properties of whole ecosystems, including productivity, nutrient cycling, and community structure and function. Further, insecticide-resistant population seems to have an edge in adapting to climate changes.

Climate change affects insects in many ways: it can cause a shift in geographical spread (Porter et al. 1991; Ward and Masters 2007), abundance (Ayres and Lombardero 2000), or diversity (Conrad et al. 2002; Feehan et al. 2009); it can change the location, the timing, and the magnitude of outbreaks of pests (Volney and Fleming 2000); and it can define the phenological or even the genetic properties of the species (Klok and Chown 2001; Gordo and Sanz 2006; Parmesan 2007). Long-time investigations of special insect populations, simulation models, and scenario studies give us very important information about the response of the insects far away and near to our century. Getting to know the potential responses of insect populations to climate change makes it possible to evaluate the pest management alternatives as well as to formulate our future management policy. Climate change resulting in increased temperature could impact crop-pest insect populations in several complex ways. Although some climate change temperature effects might tend to depress insect populations, most researchers seem to agree that warmer temperatures in temperate climates will result in more types and higher populations of insects. Researchers have shown that increased temperatures can potentially affect insect survival, development, geographic range, and population size. Temperature can impact insect physiology, metamorphosis, and development directly or indirectly. Depending on the development "strategy" of an insect species, temperature can exert different effects (Bale et al. 2002). Some insects take several years to complete one life cycle – these insects (cicadas, arctic moths) will tend to moderate temperature variability over the course of their life history.

24.2.1 Insects' Response to Elevated Temperature

Insects are poikilotherms or cold-blooded which implies that their body temperature is approximately the same as that of the environment. Therefore, temperature is probably the single most important environmental factor that could influence insect behavior, distribution, development, survival, and reproduction. Insect life stage predictions are most often calculated using accumulated degree-day from a base temperature. Some researchers believe that the effect of temperature on insects largely overwhelms the effects of other environmental factors (Bale et al. 2002). It has been estimated that with a 2°C temperature increase, insects might experience one to five additional life cycles per season (Yamamura and Kiritani 1998). It has also been found that moisture and CO_2 also affect insects in a global climate change scenario (Coviella and Trumble 1999; Hunter 2001; Hamilton et al. 2005). Current estimates of changes in climate indicate an increase in global mean annual temperatures of 1°C by 2025 and 3°C by the end of the next century. Such increases in temperature have a number of implications for temperature-dependent insects. Climate change may result in changes of geographical distribution, increased overwintering, changes in population growth rates, increases in the number of generations, extension of the development season, changes in crop-pest synchrony of phenology, changes in interspecific interactions, and increased risk of invasion by migrant pests (Porter et al. 1991; Parmesan 2007).

Several results on the effect of climate change on insects were published in the field of forestry sciences since insects cause considerable loss in wood that has an adverse effect on the balance of carbon sequestered by forests. Volney and Fleming (2000) state that forest pests have been consistently overlooked which will have serious consequences to the structure and functions of forests. Global change will have demonstrable changes in the frequency and intensity of pest outbreaks, particularly at the margins of host ranges. The connection between temperature tolerance and phenology of insects was investigated by Klok and Chown (2001). They defined how current climate change like increased temperature and decreased rainfall affects the physiological regulation and susceptibility. Powell and Logan (2005) have reviewed the mathematical relationship between temperatures and developmental dates and analyzed circle maps which predict the future oviposition dates with respect to the temperature. Applying scenarios for global warming, they proved that adaptive seasonality may break down with little warning with constantly increasing (and also decreasing) temperature. Some insects are closely tied to a specific set of host crops. Temperature increases that cause farmers not to grow the host crop any longer would decrease the populations of insect pests specific to those crops. Lower winter mortality of insects due to warmer winter temperatures could be important in increasing insect populations (Harrington et al. 2001). Higher average temperature might result in some crops being able to be grown in regions further north – it is likely that at least some of the insect pests of those crops will follow the expanded crop areas. Insect species diversity per area tends to decrease with higher latitude and altitude (Gaston and Williams 1996; Andrew and Hughes 2005), meaning that rising temperatures could result in more insect species attacking more hosts in temperate climates (Bale et al. 2002). Based on evidence developed by studying the fossil records, some researchers (Bale et al. 2002) conclude that the diversity of insect species and the intensity of their feeding have increased historically with increasing temperature. Some crop pests are "stop and go" developers in relation to temperature – they develop more rapidly during periods of time with suitable temperatures. We often use degree-day or phenology-based models to predict the emergence of these insects and their potential to damage crops, viz., cabbage maggot (*Delia radicum* (L.)), onion maggot (*Delia antiqua*), European corn borer (*Ostrinia nubilalis*), and Colorado potato beetle (*Leptinotarsa decemlineata*). Increased temperatures will accelerate the development of these types of insects – possibly resulting in more generations (and crop damage) per year. Temperature may also change gender ratios of some pest species such as thrips (Lewis 1997) potentially affecting reproduction rates.

24.2.2 Insects and Elevated CO_2

Predicted increases in atmospheric CO_2 and global mean temperature are likely to influence insect–plant interactions. Plant traits important to insect herbivores, such as nitrogen content, may be directly affected by elevated CO_2 and temperature, while insect herbivores are likely to be directly affected only by temperature. Rao et al. (2008) compiled an extensive review on the effect of elevated CO_2 on herbivore insects and their host interactions and stated that substantial changes in photochemistry of plants were reported by several workers. However, Flynn et al. (2006) stated that aphid populations did not change significantly under elevated CO_2 but tended to increase slightly. Average weight decreased at high temperatures. Plant height and biomass were not significantly affected by the CO_2 treatment, but growth rates before infestation were enhanced by elevated CO_2. These results indicate that the combined effects of both elevated CO_2 and temperature may exacerbate pest damage to certain plants, particularly to plants which respond weakly to increases in atmospheric CO_2.

Studies with free-air carbon dioxide concentration enrichment (FACE) technology were used to create an atmosphere with CO_2 and O_2 concentrations similar to what climate change models predict for the middle of the twenty-first century showed that soybeans grown in elevated CO_2 atmosphere had 57 % more damage from insects (primarily Japanese beetle, potato leafhopper, western corn rootworm, and Mexican bean beetle) than those grown in ambient atmosphere. It is thought that increases in the levels of simple sugars in the soybean leaves may have stimulated the additional insect feeding (Hamilton et al. 2005). Although not observed in the FACE study, other researchers have observed that insects sometimes feed more on leaves that have low nitrogen content in order to obtain sufficient nitrogen for their metabolism (Coviella and Trumble 1999; Hunter 2001). Increased carbon-to-nitrogen ratios in plant tissue resulting from increased CO_2 levels may slow insect development and increase the length of life stages vulnerable to attack by parasitoids (Coviella and Trumble 1999).

24.2.3 Effects of Changes in Precipitation on Insects

There are fewer scientific studies on the effect of precipitation on insects. Some insects are sensitive to precipitation and are killed or removed from crops by heavy rains. This consideration is important when choosing management options for onion thrips (Reiners and Petzoldt 2005). For some insects that overwinter in soil, such as the cranberry fruit worm and other cranberry insect pests, flooding the soil has been used as a control measure (Vincent et al. 2003). So one would expect precipitation forecast with climate change to negatively impact these insects. Other insects such as pea aphids are not tolerant to drought (Macvean and Dixon 2001). As with temperature, precipitation changes can impact insect pest's predators, parasites, and pathogen. Fungal pathogens of insects are favored by high humidity, and their incidence would be increased by climate changes that lengthen periods of high humidity and reduced by those that result in drier conditions.

24.2.4 Effect on Natural Enemies

Climate change impacts not only the pest species but also their natural enemies, viz., parasitoids, predators, and pathogens which play a crucial role in their population dynamics. Higher temperatures and CO_2 affect the tri-trophic interaction chain involving host plant, host insect, and its parasitoid or predator, resulting in changed status of biological control. At higher temperatures, aphids have been shown to be less responsive to the aphid alarm pheromone they release when under attack by insect predators and parasitoids – resulting in the potential for greater predation (Awmack et al. 1997). Changes in foliar chemistry are likely to alter interactions between herbivorous insects and their natural enemies (Rao et al. 2008). Ayres and Lombardero (2000) have shown that climate change has direct effects on the development and survival of herbivores and pathogens; physiological changes in tree defenses; and indirect effects from changes in the abundance of natural enemies, mutualists, and competitors. Variation in the quality and composition of food consumed, which is likely to result in differences in the chemical composition of the herbivore, can affect its susceptibility to predator attack (Price et al. 1980). It was reported that parasitism by hymenopteran parasitoid, *Cotesia melanoscelus*, significantly prolonged the feeding of gypsy moth on elevated CO_2-grown aspen, birch, maple, and oak, and reduced growth rates. The only significant effect of elevated CO_2 on parasitoid included an increase in mortality and decline in adult female size. The specialist parasitoid, *Cotesia plutellae*, preferred the odor of damaged plants of both cultivars (*Brassica oleracea* ssp. capitata, cvs Lennox and Rinda) grown at ambient CO_2 but did not detect damaged cv Lennox plants grown at elevated CO_2, suggesting that elevated atmospheric CO_2 concentration could weaken the plant response induced by insect herbivore feeding and, thereby, lead to a disturbance of signaling to the third trophic level (Vuorinen et al. 2004).

24.2.5 Effect on Insect Vectors

Many hemipterans like aphids and whiteflies, besides being pests, also act as vectors of dreadful viruses. Changes in host plants and insect vector populations that might result from climate change (their geographical distribution range, their densities, migration potential and phenology) could also affect the spread of plant viruses. At the individual level, alterations in plant physiological processes that are relevant to their molecular interactions with viruses, like changes in metabolism, leaf temperature, and their effects on some processes, like the temperature-sensitive antiviral resistance based on RNA silencing, can also influence the resistance/susceptibility of individual plants to viral infections. In order to assess the impact that climate change may have on the incidence and spread of vector-borne plant viruses, its potential effects on insect vectors need to be understood.

24.3 Climate Change May Enhance Biotype Emergence

It is not uncommon to face a situation where certain group of populations of a particular pest species successfully resists the management strategy. This is particularly true in herbivorous insects. When a previously successful tactic fails, the insect population has apparently adapted to it and is often considered to be a new or distinct entity and given the nonformal category "biotype." Climate change can potentially augur the process of biotype emergence, leading to further complications in pest management. Phenotypic variation is ubiquitous in natural populations. Increasingly, differentiation among populations at the intraspecific level has been seen as an important aspect in understanding biodiversity, speciation, and adaptive change. Entomologists working on pest species that vary in their responses to the methods used to control them often discuss their results in terms of population level differences. Many of these researchers have seen it fit to name or classify the variants they find under the pseudo-taxonomic category "biotype," generally naming these "taxa" with letters or numbers. It is not clear, however, if the variants so named represent genetically based phenotypic variation due to allelic, genotypic, population, or species-level differences. Since allelic and genotypic variations are transient properties of the individuals in populations, and species-level differences are the domain of systematics, it is only population level differences where intraspecific categories such as biotype can have any meaning.

24.3.1 Biotype of Whitefly, *Bemisia tabaci*: A Case Study

Bemisia tabaci (Gennadius 1889) is a cosmopolitan agricultural invasive pest. It is broadly polyphagous feeding on an estimated 900 host plants (Jones 2003; Ma et al. 2007). Identifying species boundaries within morphologically indistinguishable cryptic species complexes is often contentious. The concept of biotype in *B. tabaci* came to prominence with the invasion of the southern United States by a *B. tabaci* that behaved quite differently from the indigenous population (De Barro et al. 2011). It transmits around 111 viruses that belong to family *Geminiviridae* (Brown and Bird 1992; Jones 2003). Incompatible mating resulting in restricted gene flow has been shown between various biotypes A, B, AN, D, K, L, and M (Costa et al. 1993; Bedford et al. 1994; Byrne et al. 1995; Brown et al. 2000; De Barro and Hart 2000). Biotype B was first identified in 1999 in Kolar district of Karnataka State, India (Rekha et al. 2005). Biotype "H" was identified in Gujarat on cotton (Brown et al. 1995; Rekha et al. 2005) and in Kerala on watermelon in 1991 (Bedford et al. 1992, 1994) and biotype "I" from Maharashtra (Perring 2001). Biotype G was on cotton from Guatemala (Bedford et al. 1992, 1994; Brown et al. 2000). A report by Lisha et al. (2003) indicated that two strains, viz., cassava-strain and sweet potato-strain populations, identified to be different related to their respective hosts. There is probably an agroclimatic trend in the geographical distribution of the biotypes. For example, Biotype "H" occurs in the more humid and higher temperature areas (Gujarat and Kerala). In drier regions biotype "B" seems to be predominant in Kolar regions of Karnataka.

The relationships between plant viruses, their herbivore vectors, and host plants can be beneficial, neutral, or antagonistic, depending on the species involved (Jiu et al. 2006). This variation in relationships may affect the process of biological invasion and the displacement of indigenous species by invaders when the invasive and indigenous organisms occur with niche overlap but differ in the interactions. The notorious invasive B biotype of the whitefly complex *Bemisia tabaci* entered China in the late 1990s and is now the predominant or only biotype in many regions of the country. Tobacco curly shoot virus (TbCSV) and tomato yellow leaf curl China virus (TYLCCNV) are two whitefly-transmitted begomoviruses that have become widespread recently in south China. They compared the performance of the invasive B and indigenous ZHJ1 whitefly biotypes on healthy, TbCSV-infected, and TYLCCNV-infected tobacco plants. Compared to its performance on healthy plants, the invasive B biotype increased its fecundity and longevity by 12–6-fold when feeding on TbCSV-infected plants and by 18–7-fold when feeding on TYLCCNV-infected plants. Population density of the B biotype on TbCSV- and TYLCCNV-infected plants reached 2–13 times that on healthy plants, respectively, in 56 days. In contrast, the indigenous ZHJ1 performed similarly on healthy and virus-infected plants. Virus-infection status of the whiteflies per se of both biotypes showed limited effects on performance of vectors on cotton, a nonhost plant of the viruses. The indirect mutualism between the B biotype whitefly and these viruses via their host plants, and the apparent lack of such mutualism for the indigenous whitefly, may contribute to the ability of the B whitefly biotype to invade, the displacement of indigenous whiteflies, and the disease pandemics of the viruses associated with this vector.

24.4 Conclusion

The consequences brought out by the phenomenon of climate change may be too slow to perceive but are very certain to affect the phenology and distribution ranges of both crop plants and insect fauna associated with them, leading to temporal and spatial mismatches. It is therefore important to identify the temperature sensitivity of the most important pests, pollinators, and their crop plants and the environmental cues controlling the phenology and distribution of the identified species. Long-term monitoring of agroecosystems and experimental assessments of climate sensitivity of species will help our understanding of the impacts of climate change on insects associated with agricultural ecosystems. It is essential to evolve a simple risk assessment procedure to determine the countries or agroclimatic zones vulnerability to climate driven effects on crop pests. This review attempted to outline the possible effects of climate change on crop pests, their natural enemies, vectors, biotypes, and pollinators and the gaps in the present knowledge on the topics.

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25

Use of Degree Days and Plant Phenology: A Reliable Tool for Predicting Insect Pest Activity Under Climate Change Conditions

Vaddi Sridhar and Poluru Venkata Rami Reddy

Abstract

Insects are poikilothermic, i.e., cold-blooded, and hence the environment temperature has the greatest effect on insect development rates. In general, the development rate increases as temperature increases. However, upper and lower limits of these thresholds vary with the species. Phenology is the study of recurring biological phenomena and their relationship to weather. Bird migration, blooming of wildflowers and trees, and the seasonal appearance of insects are examples of phenological events that have been recorded for centuries. Plants bloom earlier in warm springs. Insects also emerge earlier when it is warm than in cooler seasons. Because the development of both plants and insects is temperature dependent, plants can accurately track the environmental factors that determine when insects are active. For this reason, plant phenology can be used to predict insect emergence. Plants bloom and insects emerge in virtually the same order every year, no matter what kind of weather occurred that winter or spring. Hence, the flowering sequence of plants can be used as a biological calendar to predict insect activity and to time other gardening practices that are dependent on a particular stage of plant development, such as propagation or weed control. In this chapter, methods of calculating degree days and how it is useful for prediction of plant phenology vis-a-vis insect activity are presented.

25.1 Introduction

Global warming undoubtedly impacts crop-associated biodiversity, of which insects (pests, natural enemies, and pollinators) are the important components in several complex ways. Although climate change-induced temperature effect might tend to depress some insect populations, overall warmer temperatures will result in more types and higher

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populations of insects. Increased temperatures can potentially affect insect survival, development, geographic range, and population size (Sridhar et al. 2010). Temperature can impact insect physiology and development directly or indirectly through the physiology of host. Insects emerge earlier in warmer years than in cooler ones. Since insect development is temperature dependent, monitoring degree-day accumulation is a valuable tool for predicting pest activity thereby helping in timing of treatments (Murraym 2008). Since plant development is also temperature dependent, monitoring plant phenology, such as flowering time, can be used to track degree-day accumulation and predict insect activity. If a sequence of plant phenological events can be shown to correspond with the appearance of insect pests, then the easily monitored phenological sequence could be used as biological calendar to anticipate the order and time pests reach vulnerable stages.

25.2 Role of Temperature on Growth and Development of Insects and Plants

Insects are poikilothermic, i.e., cold-blooded, and hence the environment temperature has the greatest effect on insect development rates. Growth and development of beneficial and harmful insects are dependent on several environmental factors including temperature (heat), light, and humidity. In general, the development rate increases as temperature increases. In the temperature range from 10°C to 30°C, development rate changes almost linearly with increasing temperature. At temperatures, below and above a certain threshold, there will be either no development or development is retarded. The upper and lower limits of these thresholds vary with the species.

Temperature influences plant growth in a similar manner as that of insects. Each stage of plant development requires a certain amount of heat units to advance to the next stage. This measure of accumulated heat over time is known as *physiological time*. For example, if there is a hot spell around bloom on apples, pink to petal fall stage can occur within 3–4 days compared to cool, rainy weather where bloom can extend for several weeks. The same numbers of heat units are accumulated in both situations. However, the heat units accumulate faster under warmer conditions. Theoretically, physiological time provides a common reference for the development of organisms. The amount of heat required to complete a given organism's development does not vary – the combination of temperature (between thresholds) and time will always be the same. Physiological time is often expressed and approximated in units called degree days (°D). Consult Baskerville and Emin (1969), Andrewartha and Birch (1973), Allen (1976), Zalom et al. (1983), and Wilson and Barnett (1983) for the historical development of the degree-day concept.

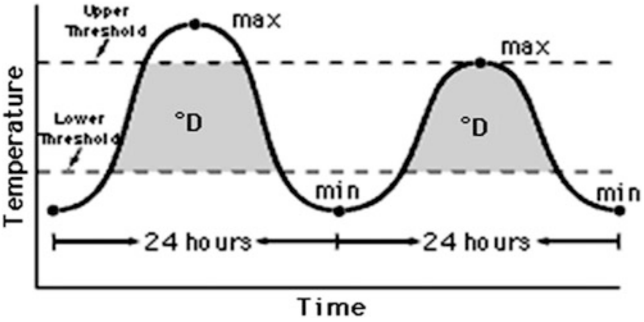
Plants bloom and insects emerge in virtually the same order every year, no matter what kind of weather occurred that winter or spring. For this reason, the flowering sequence of plants can be used as a biological calendar to predict insect activity and to time other gardening practices that are dependent on a particular stage of plant development, such as propagation or weed control or scheduling pesticide sprays.

25.3 Degree Days

For many years, growers have observed the arrival or development of a particular insect pest with flower bud or leaf development and have timed the applications of sprays in a given season. This is an indirect use of physiological time. These natural timers are most useful early in the growing season when plant growth stages are readily observable. However, accurate predictions of insect life cycle are possible if growth stages throughout the growing season are available. This is done by measuring *degree days* of the pest in question. A degree day (also referred to as a growing degree day, heat unit, or thermal unit) is a measure of the amount of heat that accumulates above a specified base temperature during a 24 h period.

Entomologists have determined lower threshold temperatures and degree-day totals for the life cycle stages of many insects by studying their development in the field and the laboratory. The lower developmental threshold for a species is the temperature below which development stops.

Fig. 25.1 Thresholds and accumulated degree days



The upper developmental threshold is the temperature at which the rate of growth or development begins to decrease. Phenology models are then developed and used to predict various events or life cycle stages of an insect. The *biofix* is the date when degree days begin to be accumulated, usually associated with a biological event, such as first sustained trap catch of males of insect pests. If 1–2 moths are collected in traps, followed by a period of no captures before resumption of more or less continuous captures, then those early males are ignored. The "sustained catch" is the beginning of the continual period of moth activity. Obviously, this cannot be determined on the day of the capture, rather only after the overall pattern of flight is seen. In practical terms, there may not be much difference between first catch and first sustained catch. If 1–2 males are captured followed by an interval of no catches caused by cool weather, then very few degree days have accumulated in the days between first catch and first sustained catch. The critical number of degree days to signal the timing of a spray may occur almost on the same date.

Figure 25.1 illustrates the relationship between time and temperature, and the accumulation of degree days. One degree day is 1 day (24 h) with the temperature above the lower developmental threshold by one degree.

25.3.1 Determination of Degree Days (DD)

There are a number of ways to calculate degree days, ranging from quite simple to those so complex that a computer is required. The Average method, the Modified Average method, and the Modified Sine Wave method are the commonly used ones. The simplest method used to estimate the number of degree days for 1 day is the Average method. In this method degree days (DD) are estimated as [(maximum temp. + minimum temp.)/2] − developmental threshold. For example, on May 14, 1998, in Bangalore, India, maximum temperature and minimum temperatures were 35 and 19°C, respectively. Using 10°C for the lower developmental threshold for tomato serpentine leaf miner, *Liriomyza trifolii*, degree days accumulated were estimated as $[(35+19)/2] - 10 = 17$ DD. Therefore, on May 14th 17 degree days were accumulated for tomato leaf miner. The Modified Average method is calculated in the same way as the Average method, except that the base temperature is substituted for the minimum temperature when the minimum temperature drops below the base temperature. This method is more suitable when the daily temperature fluctuates above and below the base temperature. The Modified Sine Wave method is even more accurate when the minimum temperature drops below the base temperature. This method makes use of the fact that daily temperature patterns closely resemble a sine wave function and determines the amount of degree days by calculating the amount of area under the temperature curve and above the base temperature (shaded portion of Fig. 25.1).

25.3.2 Accumulated Degree Days to Predict Insect Activity/Plant Development

Each developmental stage of an organism has its own total heat requirement. Development can be estimated by accumulating degree days between the temperature thresholds throughout the season. Each species requires a defined number of degree days to complete its development. The accumulated degree days from a starting point can help predict the time of developmental stage. Biofix date, the starting day of degree days accumulation varies with the species. Biofix dates are usually based on specific biological events such as planting dates, first trap catch, or first occurrence of a pest. Accumulation of degree days should be done regularly, especially when a decision of control action is nearer.

25.3.3 Steps in Construction of a Degree-Day Model

Degree days can be valuable tools for predicting insect development and timing of pest management practices. Various steps for construction of a degree-day model are presented below (Herms 2004):

1. Identify and monitor a phenological event of a plant and/or pests or beneficial insect (pollinators, predators, parasitoids etc.).
2. Determine an appropriate base temperature (lower threshold).
3. Select a starting date for degree-day accumulation.
4. Record daily maximum and minimum temperatures. Try to get the microclimate data to minimize the error, in temperature recording.
5. Calculate the number of degree days that accumulate each day.
6. When the phenological event that is being monitored occurs, note the total number of degree days that have accumulated since the starting date.
7. Use this value to predict the occurrence of the phenological event in future years (by using climate change-predicted parameters).

25.4 Predicting Insect Activity Using Plant Phenology

Plant phenological events also offer equal cues to predict insect activity. We can use plant phenological events as indicators for pest activity, particularly with reference to perennial horticultural crops. Phenology is the study of recurring biological phenomena and their relationship with weather. Bird migration, blooming of wildflowers and trees, and the seasonal appearance of insects are examples of phenological events that have been recorded for centuries. Plant phenological events, such as flowering time, can be used to track degree-day accumulation and predict insect activity, as both plants and insects respond to degree-day accumulation in the same way. The critical assumption in the use of plant phenology to predict pest activity is that the phenological sequence (the order in which phenological events occur) remains constant from year to year even if weather patterns differ greatly. Phenological sequences can be used very effectively as biological calendars for scheduling pest management. Scouting for vulnerable stages of insect pests of plants is much easier if we know when to look for them. For example, euonymus scale is a very destructive pest of evergreen euonymus (*Euonymus fortunei*), a popular landscape shrub. Euonymus shrubs can be protected from damage caused by euonymus scale by spraying infested shrubs with a 2% concentration of horticultural oil when the crawlers emerge. Although the oil spray kills about 50% of the overwintering scale insects when it is applied in April or May, it is much more effective when applied after the crawlers emerge in June under US conditions. If sprayed after most of the crawlers have emerged, horticultural oil will kill more than 90% of the crawlers, providing adequate plant protection from a single spray.

The exact week that euonymus scale crawlers emerge each year is different because plant growth and insect activity depend on temperature. In a very warm spring, the euonymus scale crawlers could emerge as early as the middle of May, or in a very cold spring, they may not emerge until late June. The time that euonymus scale crawlers start to emerge each year, and other key pest events, can be predicted accurately by the degree-day accumulation in a given area or by when certain plants are in full bloom. Phenology is the study of biological events in relation to weather. "Plant phenology" follows easily observed events such as bloom time to track the development of insect pests over the course of the growing season.

Herms (2004) used full bloom (Table 25.1) of different kinds of trees and shrubs as a biological calendar to predict when key insect pests are active. Bloom time of plants is good indicator of insect development because plants bloom earlier in a warm spring and bloom later in a cold spring. Likewise, insects emerge earlier in a warm spring and later in a cold spring. So one way to predict when euonymus scale crawlers emerge is to look for full bloom of 'Winter King' hawthorn, pagoda dogwood, or black locust.

Another way to predict when crawlers emerge is to keep track of or look up the degree-day accumulation in our area and compare it with the tree phenology. During a 5-year period, euonymus scale crawlers emerged when the degree-day accumulation (base 50°F) ranged from 517 to 678 (average 575) each year. Degree-day accumulation is a way to keep track of accumulated heat units each day of the year, starting from March 1. This has proven to be a reliable indicator of when plants bloom and when insects are active. In Table 25.1 degree days are listed as "DD50." The 50 refers to the base temperature used to calculate the degree days. Fifty degrees Fahrenheit is often used as a general base temperature for insects because most insects do not develop or grow when the temperature is below 50°F. Calculate degree days by using a maximum-minimum thermometer to take daily readings. It has to be calculated as follows: DD50 = [(maximum temperature + minimum temperature)/2]−50. Notice that in extremely cool days there may not be any degree-day accumulation.

25.5 Lower Developmental Thresholds for Few Selected Pests

As discussed above, each insect stage requires a certain number of degree days before it metamorphed to the next stage. Upper and lower developmental thresholds have been determined for many of the pests through carefully controlled laboratory and field experiments (Table 25.2).

25.5.1 Degree-Day Requirement for Serpentine Leaf Miner

For understanding the total degree-day requirements for completion of insect development, the following example is presented. Serpentine leaf miner, *Liriomyza trifolii* is one of the major pests on many horticulture crops including ornamentals and vegetables. Degree days estimated for *L. trifolii* (Miller and Isger 1985) for different stages are presented in Table 25.3.

25.5.2 Obtaining Temperature Data

It is easy to measure maximum and minimum daily temperatures using a max/min thermometer at the orchard. The thermometer should be placed in location in the orchard and protected from sun and wind, and temperature should be recorded at the same time each day. The degree days can be used to predict the pest populations in various locations of the globe which are showing differential climate projections as per the IPCC. Various software like CLIMEX/DYMEX can be used for studying the influence of degree days on the biology of the given pest on the target crop. This information can be used for the prediction of pest activity on the crop and also for taking timely management schedules.

25.5.3 Limitations of Degree-Day Models

- The major source of error in degree-day models lies in temperature data used to calculate degree days. Microenvironments in which insects exist are generally very different from environment of the thermometer used to collect the temperature data. Furthermore, some insects exert control over their body temperatures through their behavior. Recording temperatures directly in the insects' vicinity by using probe thermometers will minimize the error in recording the temperature.

Table 25.1 Prediction of insect pest activity in Michigan from full bloom of trees and shrubs or by degree-day accumulation (DD50)

Plant/pest species	Phenological event	Average date	Cumulative degree days
Silver maple	Full bloom	4-Apr	30
Eastern tent caterpillar	**Egg hatch**	**9-Apr**	**47**
Red maple	Full bloom	13-Apr	67
Border forsythia	Full bloom	22-Apr	97
White pine weevil	**Adult emergence**	**25-Apr**	**110**
Star magnolia	Full bloom	25-Apr	114
Gypsy moth	**Egg hatch**	**28-Apr**	**148**
Norway maple	Full bloom	29-Apr	154
Weeping Higan cherry	Full bloom	1-May	155
‘PJM’ Rhododendron	Full bloom	3-May	172
Amelanchier sp.	Full bloom	3-May	176
‘Bradford’ Callery pear	Full bloom	4-May	182
Hawthorn leaf miner	**Adult emergence**	**4-May**	**183**
European alder leaf miner	**Adult emergence**	**5-May**	**189**
Birch leaf miner	**Adult emergence**	**5-May**	**189**
Euonymus caterpillar	**First larva**	**9-May**	**227**
Japanese Flowering Cherry	Full bloom	9-May	227
Elm leaf miner	**Adult emergence**	**9-May**	**228**
Eastern redbud	**Full bloom**	**11-May**	**254**
‘Snowdrift’ crabapple	Full bloom	11-May	255
Pine scale	**Egg hatch**	**13-May**	**277**
Cooley spruce gall adelgid	**Egg hatch**	**13-May**	**283**
Wayfaringtree Viburnum	Full bloom	14-May	287
‘Coral Burst’ crabapple	Full bloom	14-May	296
Common lilac	Full bloom	17-May	323
Lilac borer	**Adult emergence**	**16-May**	**324**
Lesser peachtree borer	**Adult emergence**	**20-May**	**362**
Oystershell scale	**Egg hatch**	**19-May**	**363**
Doublefile viburnum	Full bloom	21-May	398
Vanhoutte spirea	Full bloom	25-May	429
‘Winter King’ hawthorn	Full bloom	29-May	485
Pagoda dogwood	Full bloom	29-May	488
Bronze birch borer	Adult emergence	2-Jun	550
Black locust	Full bloom	3-Jun	564
Peachtree borer	**Adult emergence**	**3-Jun**	**573**
Euonymus scale	**Egg hatch**	**3-Jun**	**575**
Juniper scale	**Egg hatch**	**11-Jun**	**697**
Washington hawthorn	Full bloom	18-Jun	830
Japanese tree lilac	Full bloom	20-Jun	860
Fletcher scale	**Egg hatch**	**20-Jun**	**884**
Cottony maple scale	**Egg hatch**	**23-Jun**	**930**
Northern catalpa	Full bloom	24-Jun	937
‘Greenspire’ littleleaf Linden	Full bloom	26-Jun	985
European fruit lecanium	**Egg hatch**	**29-Jun**	**1,073**
Spruce bud scale	**Egg hatch**	**4-Jul**	**1,154**

Source: Herms (2004)

Table 25.2 Lower developmental thresholds for a few pests of horticulture crops

Name of the pest	Stage of insect	Lower developmental threshold (°C)	Reference
Helicoverpa armigera	Egg	10.5	Jallow and Matsumura (2001)
	Larva	11.3	
	Pupa	13.8	
Spodoptera litura	Egg	8.0	Ranga Rao et al. (1989)
	Larva	10.0	
	Pupa	10.0	
Ceratitis capitata	Egg	11.6	Duyck and Quilici (2002)
	Larva	10.2	
	Pupa	11.2	
Ceratitis rosa	Egg	9.8	Duyck and Quilici (2002)
	Larva	3.1	
	Pupa	11.0	
Bactrocera zonata	Egg	12.7	Duyck et al. (2004)
	Larva	12.6	
	Pupa	12.8	
Bactrocera dorsalis	Egg	11.95	Yuan et al. (2005)
	Larva	11.70	
	Pupa	12.44	

Table 25.3 Degree-day requirement for *Liriomyza trifolii*

Sl. no.	Stage of the insect	Lower developmental threshold (t_{min}) in °C	Mean degree days (°C)
1	Egg	10.1	147.5
2	Larva		
3	Pupa	10.8	138.7
4	Total degree days		286.2

Source: Miller and Isger (1985)

- Generally, for calculating degree days, we assume that the development rate of insects is a linear function of temperature. However, temperature has nonlinear effects on insect and plant development, which begins to slow dramatically as the temperature approaches the upper and lower threshold.
- Degree-day models assume that development rate is only a function of temperature. However, other factors have important effects on developmental time of insects, like nutritional quality of the plants that insects feed.

Despite such limitations, degree-day models have great practical value for predicting insect and plant development in the field. For climate change research, as the temperature is the crucial variable, thermal degree day is a very useful tool for predicting the insect activity, thereby helping in pest management decisions in both time and space. Under climate change situations, studies on degree-day units and expected generation numbers can be calculated for various pests. Khalil et al. (2010) have estimated the expected generation numbers of peach fruit fly *Bactrocera zonata* under climate change based on the thermal degree days in Egypt (Table 25.4).

Calculating degree days can be an effective tool for predicting insect emergence. Biological calendars consisting of the flowering sequence of ornamental trees and shrubs can also be used quite accurately to track degree-day accumulation and predict pest activity. The use of such indicators for timing pest activity holds tremendous potential for improving the effectiveness of IPM programs in various horticultural crops under climate change situations.

Table 25.4 Comparison between degree days and generation numbers of *B. zonata* under current and expected future climate (2050–2100) in North Sinai region

No. of generation	Current climate		2050		2100	
	Days	DDUs	Days	DDUs	Days	DDUs
1	111	492	92	498	80	489
2	41	490	43	499	46	498
3	37	489	33	488	32	497
4	32	488	29	490	29	495
5	33	493	27	496	26	495
6	38	493	28	495	27	504
7			31	488	27	490
8			44	492	32	497
9					52	489
Mean	49	491	41	493	39	495

Source: Khalil et al. (2010)

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26

Plant-Pollinator Interactions: A Highly Evolved Synchrony at Risk Due to Climate Change

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Abstract

Pollinators are an important component of crop-associated biodiversity and provide an essential ecosystem service to both natural and agricultural ecosystems. Approximately 80% of all flowering plant species are specialized for pollination by animals, mostly insects. Insects and plants react differently to changed temperature, creating temporal (phenological) and spatial (distributional) mismatches with severe demographic consequences for the species involved. Mismatches may affect plant by reduced insect visitation and pollen deposition, while pollinators experience reduced food availability. The effect of climate change on pollinators depends upon their thermal tolerance and plasticity to temperature changes. Data on the impacts of climate change on crop pollination is still limited, and investigations in this direction are very limited. This chapter deals with the potential effects of climate change on pollinators, including direct effects and indirect effects through their floral resources. Measures to enhance and conserve pollinators are also suggested.

26.1 Introduction

Pollination, by simple definition, the transfer of pollen from anthers to receptive stigma, is a vital ecosystem service essential for the sustenance of plant biodiversity on the earth, which in turn supports the survival and economy of mankind. To achieve successful pollination, many angiosperms depend on external agents like animals, wind and water. However, many food crops, barring cereals, are entomophilous in nature and rely on insects for pollination. The pollinators in turn benefit by obtaining floral resources such as nectar or pollen or both. This mutualism has evolved over centuries and been helping both natural terrestrial ecosystems and man-made agroecosystems. In agroecosystems, pollinators are essential for orchard, horticultural and forage production, as well as the production of seed for many root and fibre crops. Pollinators such as bees, birds and bats affect 35% of the world's crop production, increasing outputs of 87 of the leading food crops

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worldwide, plus many plant-derived medicines in our pharmacies (FAO 2009). The total economic value of crop pollination worldwide has been estimated at €156 billion annually (Gallai et al. 2009). The dependence of ecosystems on animal pollinators is stronger in the tropics than the global average: less than 3% of all tropical lowland plants rely on wind for pollination (Kjohl et al. 2011). The area covered by pollinator-dependent crops has increased by more than 300% during the past 50 years (Aizen et al. 2008; Aizen and Harder 2009).

Major groups of pollinators include bees (*Apis* spp. and non-*Apis* sp.), wasps, butterflies, flies and beetles. European bee, *Apis mellifera*, and Indian honeybee, *Apis cerana*, are the most widely used and managed pollinators followed by bumblebees. Crops relying on bee pollination include apple, citrus, tomato, melon, strawberry, apricot, peach, cherry, mango, grape, olive, carrot, potato, onion, pumpkin, bean, cucumber, sunflower, various nuts, a range of herbs, cotton, alfalfa and lavender (Abrol 1990; Free 1993). Approximately 73% of the world's cultivated crops are pollinated by bees, 19% by flies, 6.5% by bats, 5% by wasps, 5% by beetles, 4% by birds and 4% by butterflies and moths (Abrol 2009). In the recent years, there has been a concern about declines in both wild and domesticated pollinators and parallel declines in the plants that rely upon them. A large proportion of horticultural crops are potentially vulnerable to declines in honeybees and other pollinator insects. Complete pollinator loss would translate into a production deficit over current consumption levels of −12% for fruits and −6% for vegetables. Among different factors responsible for pollinator decline are habitat loss and fragmentation, chemical intensive agriculture, invasive species and climate change (Potts et al. 2010). Climate change is thought to be one of the major threats to pollination services (Memmot et al. 2007; Schweiger et al. 2010; Hegland et al. 2009). Considering the importance of insect pollinators in horticulture, we made an attempt to review the available literature and knowledge on the potential effects of climate change on plant-pollinator interactions. It is found that systematic studies on this aspect are very few elsewhere and almost none in India, except for the very recent initiation of research projects under the umbrella of National Initiative on Climate Resilient Agriculture (NICRA) being implemented by the Indian Council of Agricultural Research (ICAR), Government of India.

26.2 Pollinator Decline: A Reality

Biesmeijer et al. (2006) showed that in the UK and the Netherlands, a 70% drop of wild flowers that require insect pollination has been recorded as well as a shift in pollinator community composition since the 1980s. Thomas et al. (2004) have found that 71% of butterfly species have decreased and 3.4% became extinct over the past 20 years, illustrating the greatest net loss compared to native vascular plants (28% decrease in 40 years) and birds (54% decrease in 20 years) of the same area in the UK. Most species of nonmigratory butterflies that reach the northern margins of their geographic ranges in Britain have declined over the last 30 years. The "pollination crisis" that is evident in declines of honeybees and native bees worldwide is due to disruption of critical balance between the two mutually interacting organisms. Anthropogenic climate change is widely expected to drive species extinct by hampering individual survival and reproduction, by reducing the amount and accessibility of suitable habitat, or by eliminating other organisms that are essential to the species in question. Changes in habitats and climates have resulted in substantial reductions in biodiversity, and evidence has been accumulating that insect biodiversity is at risk as well. Of particular concern, the pollinators and the plants that are linked to one another within communities show coincident declines. Many agricultural crops and natural plant populations are dependent on pollination and often on the services provided by wild, unmanaged, pollinator communities. Despite widespread concern about declines in pollination services, little is known about the patterns of change in most pollinator assemblages. Depending on the assemblage and location, pollinator declines were most frequent in habitat and flower specialists, in univoltine species and/or in nonmigrants. In conjunction with this

Table 26.1 Population decline of honeybees in world scenario (Source: Gallai et al. 2009)

Country	Decline (%)	Duration
Germany	57	Last 15 years
UK	61	Last 10 years
USA	>50	Last 20 years
Poland	>35	Last 15 years
India	>40	Last 25 years
Brazil	>53	Last 15 years
Netherland	58–65	Last 25 years
China	>50	Last 20 years

evidence, outcrossing plant species that are reliant on the declining pollinators have themselves declined relative to other plant species (Abrol 2009). Gallai et al. (2009) had estimated the extent of honeybee decline in last 15–25 years in different countries (Tables 26.1 and 26.2).

26.2.1 Climate Change and Pollinators

The Intergovernmental Panel on Climate Change (IPCC) reports an approximate temperature increase ranging from 1.1°C to 6.4°C by the end of this century and that the increases in temperature will be greatest at higher latitudes (IPCC 2007). The biological impacts of rising temperatures depend upon the physiological sensitivity of organisms to temperature change. Deutsch et al. (2008) found that an expected future temperature increase in the tropics, although relatively small in magnitude, is likely to have more deleterious consequences than changes at higher latitudes. The reason for this is that tropical insects are relatively sensitive to temperature changes (with a narrow span of suitable temperature) and that they are currently living in an environment very close to their optimal temperature. Deutsch et al. (2008) point out that in contrast, insect species at higher latitudes – where the temperature increase is expected to be higher – have broader thermal tolerance and are living in cooler climates than their physiological optima. Warming may actually enhance the performance of insects living at these latitudes. It is therefore likely that tropical agroecosystems will suffer from greater population decrease and extinction of native pollinators than agroecosystems at higher latitudes. Coope (1995) gives three possible responses of species to climate change, viz., adaptation to the new environment, migration to another suitable area and extinction. The first response is unlikely since expected climate change occurs too rapidly for populations to adapt by genetic change. With increase in temperatures, many species move towards poles and higher altitudes. Tropical pollinators may respond to different temperature cues than pollinator species at higher latitudes. Temperature-induced activity patterns may also differ, depending on pollinator size, age and sex. Winter temperature might also be of importance for pollinators.

The effects of climate change on pollinators depend upon their thermal tolerance and plasticity to temperature changes. There is an urgent need to investigate the thermal tolerance of important crop pollinators and differences in thermal tolerance among *Apis* species and subspecies. Environmental cues controlling the phenology of important pollinators might include maximum daily temperature, lack of frost, number of degree days (number of days with a mean temperature above a certain threshold), day length and snow cover. Bees are the most important group of pollinators, and like other insects, they are ectothermic, requiring elevated body temperature for flying. The temperature of their surroundings determines their activity (Willmer and Stone 1997). The high surface-to-volume ratio of small bees leads to rapid absorption of heat at high ambient temperatures. All bees with body weight above 35 mg (*Apis, Bombus, Xylocopa* and *Megachile*) are capable of endothermic heating (Bishop and Ambruster 1999). Behavioural responses of pollinator insects to avoid extreme temperatures have the potential to significantly reduce pollination services (Corbet et al. 1991). Shifts in climate are bound to cause changes in behaviour of pollinators. The time taken for thermoregulation at higher temperatures comes at the cost of foraging. With increase in temperatures, the efficiency of pollen removal and deposition will change, and pollinators are at risk of overheating, especially in regions where ambient temperatures are high and climatic conditions are stable. It is important to investigate the taxonomic differences in pollinator's ability to regulate body temperature and avoid overheating (Hegland et al. 2009).

Table 26.2 Economic impacts of insect pollination on major food crop and their rate of vulnerability to pollinator loss – world scenario (Source: Gallai et al. 2009)

Crop group	Total production economic value in 10^9€ (EV)	Insect pollination economic value in 10^9€ (IPEV)	Rate of vulnerability (%) (IPEV/EV)
Fruits	219	50.6	23.1
Vegetables	418	50.9	12.2
Nuts	13	4.2	31.0
Stimulants	19	7.0	39.0
Oilseeds	240	39.0	16.3
Roots and tubers	98	0.0	0.0
Spices	7	0.2	2.7
Cereals	312	0.0	0.0
Pulses	24	1.0	4.3

26.2.2 Climate Change and Floral Resources

Plant development is mainly dependent on temperature and photoperiod. As global temperatures increase, crops will be grown in warmer environments that have longer growing seasons Rosenzweig et al. (2008). An increased temperature of 1–2°C may have negative impact on crop at low latitudes and a small positive impact at higher latitudes. Crops facing water stress were found to produce less number of flowers with little attractants for pollinators (Hegland and Totland 2005). Other effects of climate change include changes in nectar and pollen amounts, quality and changes in phenology.

26.2.3 Elevated CO_2 and Pollinators

The direct effects of elevated atmospheric carbon dioxide concentrations on pollinators and their mutualistic plant hosts are difficult to predict. Indirectly, elevated atmospheric CO_2 is expected to modify ratios of carbon and nitrogen in plant tissues, possibly leading to changes in patterns of herbivory by organisms such as butterfly larvae (Rusterholz and Erhardt 1998). How this might affect communities of pollinators is uncertain. Furthermore, increasing concentrations of CO_2 in the atmosphere will probably lead to changes in plant community structure, particularly in the proportions of C_3 and C_4 plants in a given habitat (Bazzaz 1998). It is too early to say whether these effects will influence the conservation status of particular pollinator species. However, stresses to ecosystems that are caused by climate change will act synergistically with other forms of human perturbation (Myers 1992), and the results of such synergisms cannot yet be predicted.

26.3 Expected Asynchrony of Plants and Their Pollinators

Changing climates may cause changes in the time of growth, flowering and maturation of crops, with consequent impacts on crop-associated biodiversity, particularly pollinators. Key biological events such as insect emergence and date of onset of flowering need to occur in synchrony for successful pollination interactions (Abrol 2009). Effective crop pollination is heavily dependent on biological timing, of both the crop and its pollinators. Crops such as mangoes in tropical regions, or almonds or apples in temperate regions, have periods of mass blooming over relatively short periods, requiring a tremendous peak in pollinators. Climate change may have profound impacts on the timing of these events. The extreme weather events that will accompany global warming may have severe impacts on pollinators already stressed from climatic change. Insects and plants react differently to changed

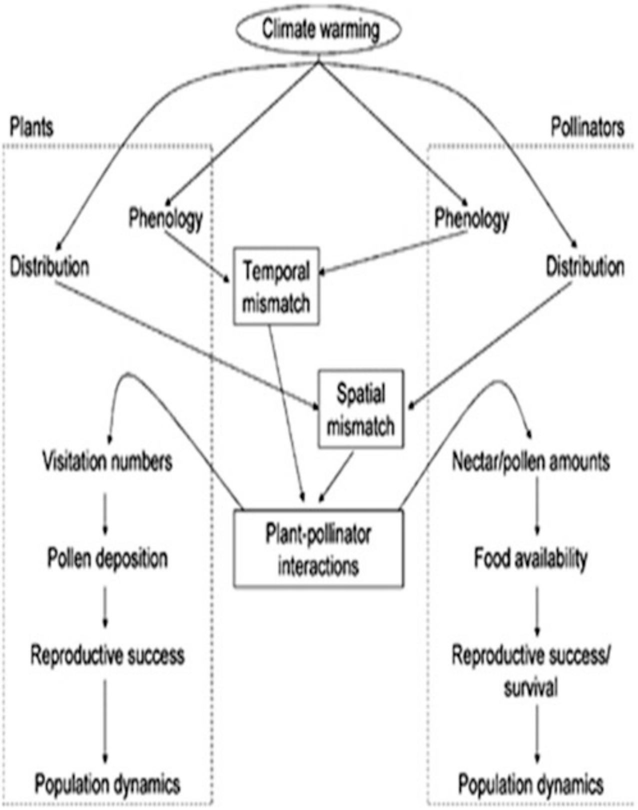

Fig. 26.1 Schematic representation of the climate change-induced effects on plant-pollinator interactions (Hegland et al. 2009)

temperature, creating temporal (phenological) and spatial (distributional) mismatches with severe demographic consequences for the species involved. Mismatches may affect plant by reduced insect visitation and pollen deposition, while pollinators experience reduced food availability. Studies have shown that there have been shifts both in the distribution and phenology of many plants and animals in the last few decades indicated by a global advancement of spring events by 2.3 days per decade and a species range shift of 6.1 km per decade towards the poles (Parmesan and Yohe 2003). Memmot et al. (2007) simulated the effect of increasing temperatures on a highly resolved plant-pollinator network. They found that shifts in phenology reduced the floral resources available for 17–50% of the pollinator species. A temporal mismatch can be detrimental to both plants and pollinators. Temperature can induce different responses in plants and pollinators. For example, increased spring temperatures may postpone plant flowering time while pollinators might be unaffected. Even if plants and pollinators do respond to the same temperature cues, the strength of the response might differ (Hegland et al. 2009). However, Kudo et al. (2004) reported that bumblebee queen emergence was unaffected by the advancement of flowering period of spring crops in Japan. Hence, the response of synchrony varies with region and species. Williams et al. (2007) found a relationship between climatic niche and declines in British bumblebees, whereas Dormann et al. (2008) projected general declines in future bee species richness in Europe. Impacts of climate change occur at all levels starting from the individual level, through population genetics, species level shifts, to the community level. Climate change-induced mismatches in temporal and spatial co-occurrence can potentially disrupt their interactions (Fig. 26.1).

26.4 Possible Measures to Conserve/Enhance Pollinators (FAO 2009)

- Giving consideration to the season-long resources needed by pollinators, both before and after crop flowering.
- Ensuring connectivity of natural habitats in farming areas so that pollinators can more easily disperse and make needed range shifts in response to changing climates.
- Measures to promote pollinators include providing more non-crop flowering resources in fields, such as cover crops, strip crops or hedgerows.

In addition, the FAO compilation by Kjohl et al. (2011) suggests that generating data on the following aspects, pertaining to both crops and pollinators, is essential to assess the vulnerability of a nation or region to pollinator loss due to climate change.

26.4.1 Crop Information

- Important crop species and cultivars
- Main system of farming; small scale versus large scale
- The value of pollinator-dependent crops by using FAO's tool for national valuation of pollination services at a national level (http://www.internationalpollinatorsinitiative.org/jsp/documents/documents.jsp)
- Number of hectares planted with pollinator-dependent crops
- Pollen and nectar flowers
- Temperature sensitivity of the most important pollinator-dependent crops obtained from http://ecocrop.fao.org/ecocrop/srv/en/home
- The metric for the risk assessment: the number of crops in the top 20 that have an upper maximum temperature of ≥30°C.
- Important environmental cues controlling the phenology of the crop plants (e.g. degree days, day length or other factors important in controlling flowering time)

26.4.2 Beekeeping

- Beehive stocks (FAO estimates)
- Honeybee subspecies
- Thermal tolerance of managed honeybees
- Assessment of the potential of introducing alternative pollinators better suited for novel climates
- Understanding the biology and ecology of alternative pollinators

26.4.3 Wild/Native Pollinators

- Knowledge of the most common wild pollinators of important crops
- Thermal tolerance of native pollinators derived from distributions (http://www.discoverlife.org/mp/20m?act=make_map)
- Upper and lower temperature averages for the locations where the wild pollinators have been collected
- Identification of groups of bees above and below the body mass limit capable of endothermic heating – 35 mg
- Important environmental cues controlling the phenology of the most important pollinators (e.g. degree days, day length, snow cover or other factors important in controlling insect activity)
- Periods of activity
- Status of surrounding vegetation, including diversity and abundance of alternative floral resources and nesting sites for wild pollinators
- Proximity to natural surroundings
- Parasites and diseases
- Trends in pesticide use

26.5 Conclusion

The consequences of climate change are of recent realization, and hence the effect of this global phenomenon on pollinator activity and their interaction with crop plants need to be understood before formulating mitigation strategies.

Though concern has been raised about the potential negative impact of climate change, there is paucity of scientific literature on how exactly pollinators are going to be affected, especially in crop plants. There is a lack of knowledge on temperature sensitivity of crop plants and their pollinators especially in the tropics where the diversity of entomophilous crops is expected to be highest. The socioeconomic consequences of reduced pollination service can be severe both in highly industrialized agroecosystems depending on large-scale pollinator farming (managed honeybees) and in more diverse small-scale agroecosystems depending on wild pollinators (Inouye 2009; Hegland et al. 2009). Hence, there is a need for more studies to increase our knowledge on the basic ecology of crop pollination under climate change to secure food production for an increasing human population.

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