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Responses of Fruit Trees to Global Climate Change



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Responses of Fruit Trees to Global Climate Change

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*Fernando Ramírez, the first author,
dedicates this work to his mother (Natalia),
Father (Fernando) and L. Marien.*

*Jose Kallarackal, the second author,
dedicates this work to his mother
(late Aleykutty), father (late Joseph) and
wife (Lilly).*

*This work is also dedicated to all
students seeking knowledge.*

Preface

Although trees have a wonderful capacity to adapt to changing climatic conditions compared to the herbaceous flora, trees that provide us edible fruits are subjected to the challenges due to global warming and the resultant climate change. Past records on phenological data from around the world have shown that the flowering of fruit trees have advanced by a few days or weeks compared to their reproductive behavior a century ago. In some locations, the increasing carbon dioxide in the atmosphere has given rise to higher productivity, while at the same time controversy remains as to whether the increasing temperature due to carbon dioxide will sustain this productivity. The change in the rainfall pattern has upset the reproductive behavior of many fruit trees, especially in the tropics.

Writing a book on the impact of climate change on fruit trees was certainly very challenging. Although quite a few research studies have been done in some of the fruit trees around the world, the results are not conclusive. This is because the climate change phenomenon itself has a long-term impact, so that after analyzing the data, it becomes difficult to synthesize them for a book. In this book, we have covered data generated in the temperate and tropical regions. It is expected that this book will prompt more research on this important group of plants, especially with the impending threat of climate change.

Fernando Ramírez
Jose Kallarackal

Contents

1	Introduction	1
	References.	2
2	Response of Trees to CO₂ Increase	3
	References.	6
3	Nutrient Value of Fruits in Response to eCO₂	9
	References.	10
4	The Effect of Increasing Temperature on Phenology.	11
	References.	12
5	Tree Phenology Networks	15
6	Phenology of Temperate Fruit Trees	19
	References.	21
7	Phenology of Sub-tropical Fruit Trees	23
	References.	24
8	Phenology of Tropical Fruit Trees	27
	References.	29
9	Climate Change and Chilling Requirements	31
	References.	33
10	Precipitation	35
	References.	36

11 Ecophysiological Adaptations and Climate Change	37
References.	38
12 Biodiversity Implications and the Spread of Diseases	39
References.	40
13 Conclusion	41
References.	42

Abstract

Increased temperature, aberrant precipitation, and a host of other related factors are expected to cause a global climate change that would adversely affect life on this planet. Fruit trees growing in a changed climate have to cope with rising CO₂ atmosphere, phenological changes occurring as a result of increased temperature, lower chilling hours (especially in the temperate regions), impact of aberrant precipitation, and the spread of new diseases. Fruit trees have ecophysiological adaptations for thriving under specific environmental conditions. Compared to natural vegetation, studies of elevated CO₂ impacts on fruit trees are limited. Global warming has caused temperate fruit tree phenology to change in various parts of the world. The chilling hours, which is a major determinant in tree phenology in temperate regions, have come down, causing considerable reduction in yield in several species. In the tropics, precipitation is a major factor regulating the phenology and yield in fruit trees. There is a need to develop phenological models in order to estimate the impact of climate change on plant development in different regions of the world. More research is also called for to develop adaptation strategies to circumvent the negative impacts of climate change. This book addresses the impact of climate change on fruit trees and the response of the fruit trees to a changing environment.

Keywords Fruit trees • Carbon dioxide • Climate change • Phenology • Chilling • Ecophysiology • Temperature

Chapter 1

Introduction

Although most angiosperm trees produce fruits, in horticultural terms, a ‘fruit tree’ is one that provides edible fruits for human consumption. Sometimes, trees producing nuts are also included in this group. The large numbers of fruit trees existing in the tropical, sub-tropical and temperate zones of the earth are important sources of food for man.

Global climate change, due to anthropogenic emission of greenhouse gases is expected to have many implications on plant life among others (IPCC 2007). This subject has received much attention from the scientists the world over as can be seen in some of the recent reviews on the subject (Morison and Morecroft 2006; Kallarackal and Roby 2012; Kallarackal and Renuka 2014). Changes in the timing of the phenophases of fruit trees or field crops could be of great economic importance, because they could have direct impacts on yield formation processes and so on the final crop yield (Chmielewski et al. 2004). A great majority of the experimental studies done on trees have been made on forest trees. Chamber experiments and Free-Air-Carbon dioxide-Enrichment (FACE) facilities have given us much information on the response of plants to increasing CO₂ in the atmosphere (Ainsworth and Long 2005). Similarly, phenological observations on many plants during the past several decades have yielded reliable data on flower and vegetative bud initiation, fruit setting and ripening, leaf growth and senescence, winter chilling and productivity, etc.

The global phenomenon of increasing CO₂ in the atmosphere will have a big impact on shaping the productivity of fruit trees in the future because CO₂ being a limiting factor in photosynthesis. Whether the ‘fertilizing effect’ of this gas, as noted in several plants, has any impact on the fruit tree photosynthesis and production is discussed in this book. Likewise, the predicted increase in atmospheric temperature, as a result of global warming will have much consequence on the physiology of flowering and fruit set in these trees. The phenological changes and the longevity of growth period noted in the different continents due to a shift in climate have been given much importance in this book. Precipitation is another

meteorological parameter going to have much temporal and spatial variations in a climate change situation. This is expected to have a major impact on the physiology of growth and reproduction of fruit trees, especially in the tropics. Finally, the ecophysiological adaptations of the fruit trees in response to climate change have been also reviewed from several studies carried out in this subject.

The purpose of this book is to give a critical look at the researches related to the horticultural fruit trees in the temperate, sub-tropical and tropical regions with a view to understand the general response of this class of trees to global climate change and also to identify the gaps in our knowledge. It is hoped that this review will give much insight into the response of climate change in fruit trees and encourage future researchers to give more attention to the gaps in our knowledge.

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Chapter 2

Response of Trees to CO₂ Increase

Among the principal abiotic requirements for plant growth, namely, light, water, nutrients and carbon dioxide, CO₂ is an anthropogenic gas associated with potential global warming. Any change in the availability of the above abiotic elements will impact not only plants, but the entire living systems. The current annual rate of increase in CO₂ (~0.5 %) is expected to continue with concentrations exceeding 600 ppm by the end of this century from the current 380 ppm (Houghton et al. 2001). Such an increase in the CO₂ levels will certainly affect the globally important process of photosynthesis, which sustains the life on this planet. Hence this has been the subject of intensive research during the past half a century. Since this book is going to deal with only the impact of climate change on fruit trees, the reader is referred to a number of general publications on this subject (e.g. Koch and Mooney 1996; Murray 1997; Luo and Mooney 1999; Reddy and Hodges 2000; Karnosky et al. 2001; Ziska and Bunce 2006; Kallarackal and Roby 2012). It is important to remember that as the methodology for artificial CO₂ enrichment experiments is improving around the groups concentrating on this research, our understanding of the response of plants to elevated CO₂ has been changing. All methods used during the past, namely, chamber methods and Free-Air-Carbon dioxide-Enrichment (FACE) have both positive and negative attributes and hence data obtained through any method should be treated with caution. Moreover, there is much interaction of CO₂ with other biotic and abiotic factors, which is usually ignored in many studies.

The primary effects of rising CO₂ on plants have been well documented and include reduction in stomatal conductance and transpiration, improved water-use efficiency, higher rates of photosynthesis, and increased light-use efficiency (Fig. 2.1) (Drake and González-Meler 1997). As may be noticed in the review on FACE facilities around the world, hardly any of them concentrate on horticultural tree crops (Ainsworth and Long 2005). Very few studies are available for fruit trees in open or closed chambers too.

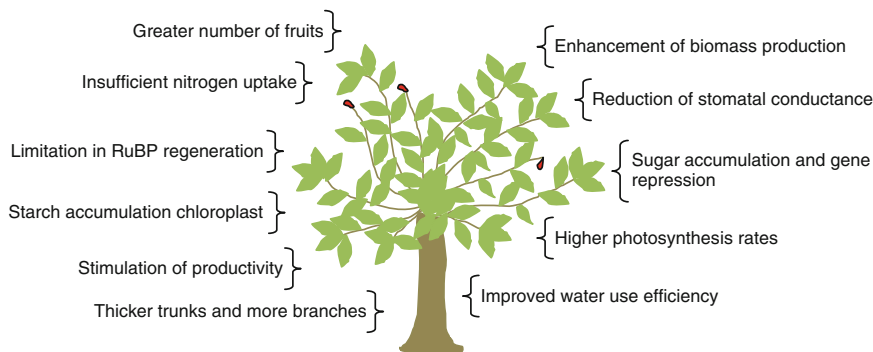


Fig. 2.1 Effects of elevated CO₂ on trees

Although photosynthesis is stimulated to approximately 37 % in the short-term elevated CO₂ experiments (Farquhar et al. 1980), when the CO₂ is raised from an ambient level of 350–550 ppm at 25 °C, over time the photosynthetic rates decline in some species relative to plants grown at ambient levels of CO₂. This phenomenon termed photosynthetic acclimation, although not very common, is reported in several species (Thomas and Strain 1991; Hogan et al. 1996). This acclimation at elevated CO₂ has been ascribed to at least five potential mechanisms at the cellular level: (a) sugar accumulation and gene repression (Krapp et al. 1993), (b) insufficient nitrogen uptake by the plant (Stitt and Krapp 1999), (c) a tie-up of inorganic phosphate with carbohydrate accumulation and a subsequent limitation in RuBP regeneration capacity (Sharkey 1985), (d) starch accumulation in the chloroplast (Lewis et al. 2002), and (e) triose phosphate utilization capability (Hogan et al. 1996).

An important point to be discussed with regard to the impact of elevated carbon dioxide (eCO₂) on fruit trees is the stimulation of productivity as noticed in certain other crops. In general, the FACE studies have reported 47 % stimulation in photosynthesis in trees compared to 7–8 % stimulation in yield in crops such as wheat or rice (Kim et al. 2003; Kimball et al. 1995; Ainsworth and Long 2005). However, in chamber studies the reports have been just the opposite, where the trees have not responded as in FACE experiments and the annual crops have responded much better. Many projections on the future food productivity have been made based on chamber studies, which would prove wrong if FACE studies are taken into account. Most of the increase in productivity reported for trees in FACE studies shows an increase in vegetative biomass including leaf area. Does it mean that only vegetative productivity is increased due to an elevation in CO₂ in the atmosphere? If productivity cannot be translated to reproductive parts, then we cannot expect the horticultural fruit crops to yield more.

When compared to the natural vegetation, studies on eCO₂ impacts on fruit trees are very limited. Sour orange trees grown for 17 years in open-top chambers reported by Kimball et al. (2007) in eCO₂ atmosphere is probably the longest experiment available for any fruit tree. Two to four years into the experiment, there

was a productivity plateau, and at about a 70 % enhancement of annual fruit and incremental wood production over the last several years of the experiment. When summed over the duration of the experiment, there was an overall enhancement of 70 % of total biomass production. Much of the enhancement came from greater numbers of fruits produced, with no change in fruit size. Thicker trunks and branches and more branches and roots were produced, but the root/shoot ratio was unaffected. Also, there was almost no change in the elemental composition of the biomass produced, perhaps in part due to the minimal responsiveness of root-symbiotic arbuscular mycorrhizal fungi to the treatment.

In *Citrus aurantium*, Idso et al. (2002) observed a long-term 80 % increase in trunk, branch and fruit biomass in response to a 75 % increase in atmospheric CO₂ concentration. They were able to recover from the soluble fraction three CO₂-sensitive proteins with apparent molecular masses of 33-, 31-, and 21-kDa, which they concluded as vegetative storage proteins (VSPs). According to them these storage proteins possibly enhance the growth due to eCO₂. The existence of these proteins may be the key that allows the CO₂-enriched trees to temporarily stockpile the unusually large pool of nitrogen that is needed to support the large CO₂-induced increase in new branch growth that is observed in the spring, which ultimately sustains the large increase in wood and fruit biomass production throughout the rest of the year. Penuelas et al. (1997) have reported that the nitrogen concentrations of leaves of sour orange (*Citrus aurantium* L.) trees growing in the field with 700 ppm CO₂ were considerably less than those of leaves on trees growing in ambient air of 400 ppm CO₂ after three years of a long-term experiment (Idso and Kimball 1997). However, by the time 8 years had elapsed the nitrogen concentrations of the CO₂-enriched leaves had gradually risen to become identical to those of the ambient-treatment leaves. This suggests that given enough time or a slow enough change in atmospheric CO₂ concentration, plants may be able to adjust their rates of nitrogen acquisition to maintain foliage nutritive characteristics similar to those of the recent past, that is, when CO₂ concentrations were somewhat lower than they are today (Newbery et al. 1995). Expressed on a per-unit-leaf-area basis, leaves from the CO₂-enriched trees contained 4.8 % less chlorophyll and nitrogen than leaves from the trees exposed to ambient air. Because of their greater leaf numbers, however, the CO₂-enriched trees contained 75 % more total chlorophyll and nitrogen than the ambient-treatment trees; the total productivity of the CO₂-enriched trees was 175 % greater. Consequently, although per-unit-leaf-area chlorophyll and nitrogen contents were slightly lowered by atmospheric CO₂ enrichment in their experiment, their use efficiencies were greatly enhanced (Idso et al. 1996).

It has been demonstrated by Rogers et al. (1996) and Kimball et al. (2001) that the provision of high levels of nitrogen fertilizer to the soil has the capacity to totally offset the reduced foliage nitrogen concentrations caused by higher levels of atmospheric CO₂. As Rogers et al. (1996) have described it, “the widely reported reduction in leaf or shoot nitrogen concentration in response to elevated CO₂ is highly dependent on nitrogen supply and virtually disappears when nitrogen is

freely available to the roots.” This probably means that we have to supplement the soil with more nitrogen in a climate change situation to maintain the productivity.

Vu et al. (2002) found that in Ambersweet orange (*Citrus reticulata*) grown for 29 months under eCO₂ in temperature gradient greenhouses, in the absence of other environmental stresses, photosynthesis would perform well under rising atmospheric CO₂. Their results show a photosynthetic acclimation for both new and old leaves of Ambersweet orange to eCO₂. This photosynthetic acclimation was accompanied by down-regulation of rubisco protein concentration and activity, and was correlated with high accumulation of starch and sucrose. The new leaves acclimated very well to eCO₂, compared to old leaves, in terms of gas exchange parameters, photosynthetic capacity and sucrose synthesis. In addition, starch accumulation in new leaves during the day was much higher than in old leaves under eCO₂. According to them photosynthetic acclimation of both young and mature leaves of Ambersweet orange to a future rise in atmospheric CO₂ would allow an optimization of plant nitrogen use, either by reallocating the nitrogen resources away from rubisco to other catalytic or structural proteins within the leaves, or redistributing nitrogen from the photosynthetic proteins of source leaves to sink tissues (Stitt 1991; Bowes 1993). Also, the optimization of inorganic carbon acquisition and greater accumulation of the primary photosynthetic products would be beneficial for citrus vegetative growth. In the above study, the productivity aspects of this crop have not been considered.

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Chapter 3

Nutrient Value of Fruits in Response to eCO₂

There have been some studies related to the impact of eCO₂ on the change in nutrient constituents of plants exposed to eCO₂ continuously. Probably the most comprehensive investigation of CO₂ effects on vitamin C production in a horticultural crop—sour orange—was conducted by Idso and Idso (2001). In an atmospheric CO₂ enrichment experiment started in 1987, a 75 % increase in CO₂ content was observed to increase sour orange juice vitamin C concentration by approximately 5 % in average-type years when total fruit production was typically enhanced by 75 %. In abnormal years when the CO₂-induced increase in fruit production was greater, however, the increase in fruit vitamin C concentration was also greater, rising to 15 % when fruit production on the CO₂-enriched trees was 3.6 times greater than it was on the ambient-treatment trees. These findings have great significance for prevention of diseases such as scurvy and common cold in many countries where the intake of vitamin C is low and could be a positive impact of rising CO₂ in the atmosphere.

Schaffer et al. (1997) have reported the effect of eCO₂ on two mango varieties grown in the green house. They have observed significant increase in leaf area and dry mass in plants grown at 700 ppm CO₂ compared to plants grown at 350 ppm. There was also significant decrease in the minerals in the vegetative tissues in plants grown in eCO₂. However, there was no report on the economic yield of trees in response to eCO₂ treatment as the plants were grown in eCO₂ only for 12 months.

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Chapter 4

The Effect of Increasing Temperature on Phenology

The word phenology emanates from the Greek word *phainó*, meaning ‘I reveal’. Phenology is the study of periodic biological events, such as bud break, flushing, flowering and fruit development, closely regulated by climate and seasonal changes, which affect fruit trees among other plants (Cautín and Agustí 2005). Higher temperatures generated as a consequence of global warming are responsible for a reduction or increase in phenological cycles in trees (Fig. 4.1). Horticultural fruit tree phenology has been impacted over the past by global warming. This is evidenced in species such as: apple (Guédón and Legave 2008; Legave et al. 2008, 2009a, b, 2013; Romanovskaja and Bakšienė 2009; Hoffmann and Rath 2013), pear (Guédón and Legave 2008), peach (Luedeling et al. 2009), plum (Cosmulescu et al. 2010) apricot (Luedeling et al. 2009), cherries (Primack et al. 2009), olive (Orlandi et al. 2010; Perez-Lopez et al. 2008) and almond (Campoy et al. 2011).

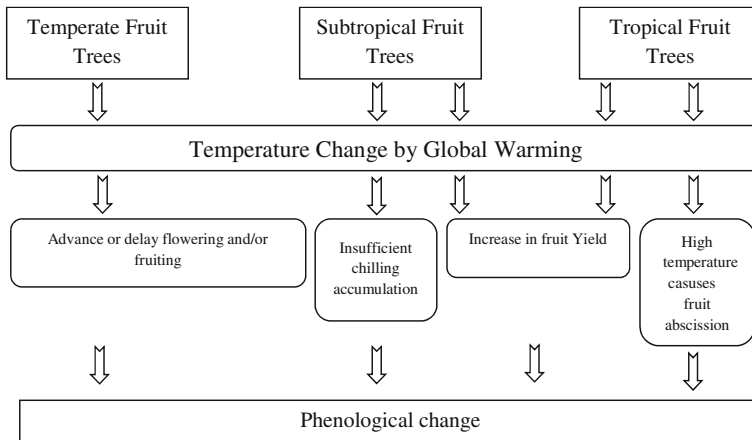


Fig. 4.1 Responses of fruit trees to temperature change in a global warming context. Note how temperature change leads to phenological modification

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Chapter 5

Tree Phenology Networks

In recent years, the involvement of the general public and school students in monitoring the environment has gained popularity. This has been achieved with the development of ‘citizen-science’ initiatives. Citizen-science networks are being used extensively in phenology research and provide valuable data to determine climate change impacts. These networks also help raise awareness among the non-scientific community of potential environmental threats. Nature enthusiasts and farmers have been following the phenology of various plants for the last few centuries. However, many of these data remained as the private property of the collectors themselves or totally lost. Recently, as studies on climate change have been taken up by many organizations, much of the phenological data are getting reassembled and wide networks of volunteer observers have been formed. With the wide use of internet, much of these data are available for the user.

The California Phenology Project (CPP) is one such network project developed with the purpose of public education and outreach along with sound scientific practices and outcomes to inform natural resource management for 19 National Park Service units in California, USA. The primary goal of the CPP is to organize and implement integrated phenology monitoring projects under a collaborative science framework across California parks and partners. The project is expected to assess how phenology can best be used to monitor the response of natural resources to climate change across California’s diverse landscape. The project also intends to identify and summarize legacy phenology datasets in California to provide a historical context for current monitoring and educational activities (see <http://www.nps.gov/lavo/naturescience/phenology.htm>).

Another wide network on phenology is the USA National Phenology Network which promotes broad understanding of plant and animal phenology and its relationship with environmental change. The Network is a consortium of individuals and organizations that collect, share, and use phenology data, models, and related information (see <https://www.usanpn.org>). Similarly, there is a citizen science program coordinated by the Appalachian Mountain Club including tracking seasonal changes of plants and animals along the Appalachian Trail, from Maine to

Georgia and also documenting alpine flowering and fruiting times on high peaks in the New England area (see <http://newengland.stewardshipnetwork.org/citizen-science/amcs-mountain-watch-phenology-program>). “Project Budburst” is another very enthusiastic programme spread over the entire USA. This is a national field campaign designed to engage the public in the collection of important ecological data based on the timing of leafing, flowering, and fruiting of plants. Project BudBurst participants make careful observations of these plant phenophases. Thousands of people from all 50 states in the USA are participating in this project. Project BudBurst began in 2007, and the observation data is available for downloading and analysis (see <http://budburst.org>). The New York Botanical Garden’s *Citizen Scientist Phenology* programme has been monitoring the phenology of native plants in the forest for nearly a decade. The Garden has partnered with the National Phenology Network to develop a long-term dataset that will show how a changing climate is impacting native plants in the forest.

New Zealand Plant Conservation Network is another network based in New Zealand in which any observer can report the phenophases of any plant in New Zealand. Their website gives help for identifying any plant in the country (see <http://www.nzpcn.org.nz>).

The Woodland Trust in the United Kingdom, apart from helping in conservation of native plants in the country has a programme named ‘Nature detectives’ mainly enthruse the youth in seasonal changes happening to plants, phenology (see <http://www.naturedetectives.org.uk>). The Swedish National Phenology Network (SWE-NPN) is collaboration between universities, governmental agencies, and volunteers. Their main goal is to collect, store and provide long-term environmental assessment data on phenology. SWE-NPN is also aiming to be a meeting place, where agencies and organizations are welcome to initiate and develop ideas related to phenology. SWE-NPN collaborates with national phenology networks in other countries and is a member of the Pan European Phenology Project (PEPP) (see <http://www.slu.se/en/collaborative-centres-and-projects/swedish-national-phenology-network>).

Ireland’s National Phenology Network (IE-NPN) was established to coordinate phenological activity throughout the country. The number of designated phenological recording sites was expanded to include International Phenological Gardens (IPG) sites and a series of native species gardens. The combined networks will enable comparison of the timing of phenological phases of a range of trees at a European level using the IPG data and at a national level using the native species. Ireland’s National Phenology Network is also the contact point for collaboration with other similar networks around the world, such as the national phenology networks in Sweden (SWE-NPN) and the USA (USA-NPN), Nature’s Calendar in the UK and many others. Research activity is a key focus of IENPN and a number of historic datasets have been identified and analyzed in relation to temperature variables to determine if global warming has had an impact on plants, birds and insects in the Irish environment. An advance in the timing of key spring phenophases of plants (leaf unfolding of a range of trees has occurred since the 1970s and this can be attributed, at least in part, to rising spring temperature).

The German Weather Service has a phenological network with data going back to the year 1530. A comprehensive list of phenology networks around the world is given by the Potsdam Institute for Climate Impact Research (see <http://www.pik-potsdam.de/~rachimow/epn/html/frameok.html>) which is supported by the European Phenology Network (EPN).

In India also, a couple of networks have started recently which are aimed at recording phenophases of many tropical trees (see <http://treecalendar.org> by the Kerala Forest Research Institute and the National Centre for Biological Sciences and <http://www.seasonwatch.in>).

Chapter 6

Phenology of Temperate Fruit Trees

In terms of productivity, climatic change may affect temperate fruit trees differently according to the production system, species, cultivar and area (Campoy et al. 2011). Global warming has caused apple tree phenology to change in various parts of the world. This is the case of apples which begin flowering 3–4 days earlier than other fruit trees in Lithuania (Romanovskaja and Bakšienė 2009). ‘Golden Delicious’ apple trees have flowered 7–9 days earlier at Conthey (Switzerland), Angers and Nîmes (France) and Forlì (Italy) regardless of regional differences since the end of the 1980s (Legave et al. 2009a). Acceleration of bud initiation and flowering can be regarded as a sign of temperature increase (Fujisawa and Kobayashi 2007). The beginning of apple growing season is getting earlier due to increasing temperature and flowering date in Nagano Prefecture, Japan. The flowering season has become 6.3 days earlier for the past 30 years (Fujisawa and Kobayashi 2010).

On the other hand, apple trees have also experienced advances in flowering date as a consequence of increasing annual mean temperatures. This is the case of ‘Golden Delicious’ apples in France that have advanced in flowering of 7–9 days (Guédon and Legave 2008; Legave et al. 2009b). Besides, Legave et al. (2013) found that blooming advances in Europe, have been more pronounced in northern continental regions such as Bonn and Gembloux (10 days) than in western oceanic regions such as Angers (6–7 days), while the shortest advance was found on the Mediterranean coastline at Forlì and Nîmes.

Climate change has also impacted other fruit trees by flowering advance. For example, in ‘Luizet’ apricot flowering period advanced by 12 days at Conthey, Switzerland (Legave et al. 2009a). It was estimated that the increase in temperature due to global warming was 1 °C at Conthey. Pear tree cultivars Williams, Passe Crassane, Doyenné du Comice have shown higher mean flowering advances (10–11 days) in France and Switzerland (Guédon and Legave 2008; Legave et al. 2009a). Pears exposed to high temperatures (28–30 °C) had less vigorous shoot growth, lower sprouting rate of flowering and vegetative shoots (Rakngan et al.

1996). Bon Chrétien pear had advanced flowering by 1.6 days in South Africa (Grab and Craparo 2011).

Japanese cherry trees such as: *Prunus lannesiana*, *P. jamasakura*, and *P. xyedoensis* and other species, flowered earlier over time, by an average of 5.5 days over the 25-year reporting (Miller-Rushing et al. 2007). Cherry trees representing 17 species and hybrids of cherry (*Cerasus* sp. or *Prunus* sp.) flowered earlier over time, by an average of 5.5 days over the 25-year reporting at Mt. Takao, in Tokyo, Japan. Earlier flowering was explained largely by a 1.8 °C increase in February–March mean monthly temperatures, however, *Cerasus campanulata* and its hybrids flowered up to 9 days earlier for each 1 °C increase in temperature (Miller-Rushing et al. 2007). In warm springs *C. campanulata* and its hybrids flowered very early, whereas in cold springs they flowered at about the same time as other taxa (Miller-Rushing et al. 2007). It is possible that most closely related species respond similarly to temperature, except for some exceptional species as it was examined for cherries (Miller-Rushing et al. 2007). The relationship between phenology and temperature may not necessarily be linear and thus a given species may respond differently to climate warming in different geographic settings (Primack et al. 2009).

Flowering in plum tree cultivars (*Prunus domestica* L.) occurred 12–20 days earlier than normal in 2007 at Cracovia, Romania (Cosmulescu et al. 2010). Gong et al. (1984) using the historical phenological data (flowering dates of *Prunus davidiana*, *Prunus persica*, *Prunus armeniaca*, *Syringa oblata*, etc.) and other evidence, as well as the modern phenological data since 1950, reconstructed the spring phenological series from 1849 to 1981 in Beijing, China. They concluded that the onset of spring phenology has advanced by 2.8 days since 1959. Flowering dates of *Prunus yedoensis* were significantly influenced by the monthly mean temperatures of January (winter), March and April (spring) in Japan and South Korea. It is estimated that if the mean temperature increased by 1 °C in March, the flowering date of *Prunus yedoensis* would advance by 3–4 days (Park-Ono et al. 1993). Similarly, if the monthly mean temperature increased by 1 °C, the flowering dates of *Prunus yedoensis* and *Prunus mume* would advance by 2.7–4.8 days and by 4–13 days respectively in Japan (Kai et al. 1993). Climate change could have large impacts on suitable tree species in the eastern United States region, especially under a high emissions trajectory (Iverson et al. 2008). In this region, black cherry (*Prunus serotina*) will diminish its habitat area as a consequence of climate change.

In Germany, phenological phases of the natural vegetation as well as of fruit trees and field crops have advanced clearly in the last decade of the 20th century (Chmielewski et al. 2004; Menzel et al. 2006). All plants showed an advanced timing of phenophases, mainly in spring, which was well correlated with the beginning of the growing season. The strongest seasonal changes in air temperature will occur in winter and in summer. For the spring development of plants mainly the temperature changes in winter and early spring are important, which steer the period of dormancy and ontogenetic development (Chmielewski et al. 2004).

The Himalayan mountain ecosystem, at present, is facing the challenges created due to increasing aridity, warmer winter season, variability in precipitation, and unexpected frosts and storms (Basannagari and Kala 2013). The Himalayas harbour

rich biodiversity and is one of the most vulnerable mountain ecosystems to climate change (Xu et al. 2009). In Himachal Pradesh, India, the area under apple has increased from 400 ha in 1950–1951 to 3,025 ha in 1960–1961 and further 99,564 ha in 2009–2010 (Anonymous 2006). However, apple tree productivity has declined (Basannagari and Kala 2013). According to Basannagari and Kala (2013), the grower's perception on the influence of climate change on apple production suggests that increasing temperature has been responsible for decline in fruit size and quality. The growers reported many indicators of climate change that impact apple farming along an altitudinal gradient. Infestation of pest and diseases such as apple scab, scale root and canker were some of the indicators of climate change that increased the cost of production due to increase in use of pesticides and chemical fertilizers (Basannagari and Kala 2013). Moreover, in the Himalayan region very little research has been conducted on phenology and climate change. Most investigations have dealt with growers perceptions of climate change (Vedwan and Rhoades 2001; Singh et al. 2009; Chaudhary and Bawa 2011; Manandhar et al. 2011; Basannagari and Kala 2013), but no direct investigation has tackled the problem of climate change and phenology in fruit trees.

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Chapter 7

Phenology of Sub-tropical Fruit Trees

Climate change studies have mostly focused on temperate fruit trees. A few sub-tropical fruit trees have attracted interest from researchers, since crops such as citrus, avocado and mango are economically important in places in the southern United States and some countries in southern Europe and Asia. Fruit tree species studied in the subtropics in relation to phenological changes due to climate change include many citrus species (Chang 2002), apple (Grab and Craparo 2011; Petri et al. 2012), mango (Sthapit et al. 2012), litchi and macadamia (Olesen 2011). Tubiello et al. (2002) simulated the effects of current and projected future climate on 'Valencia' oranges across the southern United States. They found that simulated fruit production greatly benefited from the projected climate change. Yields increased 20–50 %, while irrigation water use decreased. Crop loss due to freezing would be 65 % lower on average in 2030 and 80 % lower in 2090, at all locations where the projected effects on climate change were projected. Although the above picture of productivity is very optimistic, it will be necessary to reanalyze the above projections in the light of soil nutrient availability and pest and disease attacks. A temperature rise in Taiwan is favorable for various citrus species such as ponkan, tankan and wentan, but not for liucheng, lemon and grapefruits (Chang 2002).

Growing apples in the warm winter regions where the chilling requirement is not adequate, can cause the trees to develop a series of anomalies in the phenology referent to bud break, flowering, growth and development of both fruits and trees (Petri et al. 2012). Insufficient chilling accumulation of apple buds has been known to induce prolonged bloom period in subtropical Brazil compared to temperate regions (Petri et al. 2012). Erratic bud break and flowering observed in apple from warm regions has occurred due to maximization of the heterogeneity of the buds to chilling requirement and to the negative influence of the paradormancy promoted by the vigorous and advanced buds (Petri and Leite 2004). 'Golden Delicious' 'Sayaka' and 'Granny Smith' apple trees had advanced blooming dates on average by +1.6 days/decade over the last 37 years in the Elgin-Villiersdorp-Vyeboom region of the southwestern Cape, South Africa (Grab and Craparo 2011). Olesen (2011) examined

the late 20th century warming in a coastal horticultural region and its effects on tree phenology at Alstonville, northern New South Wales, Australia. Estimates of spring custard apple flower development time decreased by approx. 13 days (20 %) from 1963/64 to 2008/09; estimates of autumn litchi flush development decreased by approx. 8 days (7 %); estimates of winter macadamia flush development decreased by approx. 17 days (12 %) but summer flush development was not affected; and estimates of mango fruit development decreased by c. 12–16 days (7–8 %) depending on the variety. The implications of climate change for mango harvest are largely passive because there is currently little scope to manipulate flowering time (Olesen 2011) although there is increasing research into the promotion of out-of-season flowering (Ramírez et al. 2010a, b; Ramírez and Davenport 2012a, b). With custard apple, there is scope for a far more active response because flowering can be forced at any time during the growing season, allowing growers to stagger harvests (Olesen 2011). Litchi is the clearest example at present, and the recommended pruning times in summer or early autumn (Menzel 2002) for the Australian litchi industry would need to be reassessed in the advent of pronounced climate change (Olesen 2011). Early mango flowering in the sub-tropics may result in a low fruit set because of several abnormalities caused due to low night temperatures coupled with unseasonal rains (Sthapit et al. 2012). Low day temperatures cause reduced pollinator activity resulting in poor fruit set. Late flowering also reduces the fruit set because of pseudo-fruit setting leading to clustering disorder (Sthapit et al. 2012).

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Chapter 8

Phenology of Tropical Fruit Trees

Less is known about the effects of climate change on fruit trees in tropical environments. In the tropics, research has focused on mangosteen (Boonklong et al. 2006), mango (Ramírez and Davenport 2012) (Fig. 8.1) and coffee (Paes de Camargo 2010). In tropical ecosystems, phenology might be less sensitive to temperature and photoperiod, and more tuned to seasonal shifts in precipitation (Reich 1995; Morellato 2003; Sanchez-Azofeifa et al. 2003; Cleland et al. 2007; Kallarackal and Roby 2012; Kallarackal and Renuka 2014). However, this might only be applied to some species as there are specific responses depending on intrinsic features. For example, Ramírez et al. (2014) suggested that mango trees have no distinctive phenology but instead display a set of easily identifiable stages that occur independently on individual stems and are closely linked to temperature, the age of the previous vegetative flush of that stem, precipitation, and dry seasons which are the key events in the tropics (Ramírez et al. 2014). Climate change has been known to impact mangosteen (*Garcinia mangostana* L.) production in Thailand. Boonklong et al. (2006) found that mangosteen production in Thailand's eastern region increased as the drought period before flowering increased. Therefore, mangosteen production should be higher in a year that has a longer drought period (Boonklong et al. 2006). This is a likely consequence of the minimum temperature increase that has occurred over the years in the eastern region. Moreover, there has been no change in the maximum temperature. High temperature confers less fruit developmental time in the eastern region, when compared to Thailand's southern region. However, a warmer climate scenario (2–5 °C) could yield both negative and positive impacts on crop productions depending on location, and types of crops (Southworth et al. 2000). Boonklong et al. (2006) concluded that potential future adaptations to climate change for mangosteen production would require mangosteen varieties that have an increased tolerance to drought before flowering and/or an increased tolerance to minimum temperatures.



Fig. 8.1 Mango trees in Colombia showing fresh vegetative growth instead of flowers due to unusual rains

Other species in the tropics such as longan (*Dimocarpus longan* Lour.) and mango (*Mangifera indica* L.) have been exposed to increasing temperatures from 30 to 36 °C (increments of 3 °C were made every 1.5 h). As the temperature increased, stomatal conductance decreased and intercellular CO₂ concentration increased for both species, especially in longan (Yamada et al. 1996). Only a partial stomatal closure was observed even at high temperatures and mango leaves are more adaptable to high temperatures and irradiance than are longan leaves (Yamada et al. 1996). Excessively warm temperatures during the bloom or early fruit set period are known to induce fruit abscission in Citrus (Moss 1970; Rosenzweig et al. 1996). Moreover, Sthapit et al. (2012) reported that climate change will have both positive and negative impacts on fruits in tropical regions. In regions where the prevailing temperatures are already high, further increases in temperature will adversely affect the yield and quality of fruits. In regions where cold temperatures are one of the primary factors limiting crop production, temperature increases could be beneficial (Sthapit et al. 2012). However, it is important to work out the interaction of temperature and rainfall in determining productivity especially in the tropics.

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Chapter 9

Climate Change and Chilling Requirements

Climate change has affected the rates of chilling and heat accumulation, which are vital for flowering and production, in temperate fruit trees (Guo et al. 2014). All economically important fruit and nut tree species that originated from temperate and cool subtropical regions have chilling requirements that need to be fulfilled each winter to ensure homogeneous flowering and fruit set, and generate economically sufficient yields (Westwood 1993; Luedeling et al. 2009a; Luedeling and Brown 2011). Reduced winter chill is likely to have the most severe consequences for fruit production (Luedeling et al. 2011; Darbyshire et al. 2013). This chronic and steady reduction in winter chilling is expected to have deleterious economic impact on fruit and nut production in California, USA by the end of the 21st Century. Baldocchi and Wong (2008) computed trends in accumulated fruit and tree nut crops (almond, apricot, European pear, European peach, fig, nectarine, peach, persimmon, pistachio, pomegranate, quince, raspberry, sweet cherry and walnut) chilling hours and chilling degree-hours at over thirty sites in the Central Valley and coastal valleys in California. They tested the hypothesis that global warming is in motion in California and is causing accumulated winter chilling to decrease across the fruit and nut growing regions of California. They found that the annual accumulation of winter chilling hours and chilling degree hours is diminishing across the fruit and nut growing regions of California and observed trends in winter chilling range between -50 and -260 chilling hours per decade (Baldocchi and Wong 2008). Predicted rates of reduced winter chilling, for the period between 1950 and 2100, are on the order of -40 h per decade. Increases in winter chilling hours in cold areas are less likely to lead to disruptions in fruit production (Luedeling et al. 2011). Observed historic and future projected temperature increases in California strongly decreased the availability of winter chilling under all greenhouse gas emissions scenarios, using models to quantify this important climatic parameter for fruit production. On a global scale, it is likely that most other growing regions of subtropical fruit and nut trees with chilling requirements will be similarly affected by declining winter chilling (Luedeling et al. 2009a). For species above 1,000 chilling hours, such as apples, cherries and pears, very few locations in

California with satisfied chilling levels were found to exist today, and modeling results project that virtually none will exist by mid-century (Luedeling et al. 2009a). Other studies have documented a decrease in chilling hours in high-elevation oases by an average of 1.2–9.5 h/year between 1983 and 2008 in the Arabian Peninsula. This is evidenced in the two climate change scenarios where pomegranates, the most important fruit crop, received insufficient chilling by 13 and 75 %, respectively (Luedeling et al. 2009b). Long-term temperature records indicated that the number of chilling hours decreased markedly over the past 24 years. This decline is likely to cause almost complete crop failure of pomegranate, peach (*Prunus persica* L.), and apricot (*Prunus armeniaca* L.) in the oases at intermittent altitudes and very low yields (Luedeling et al. 2009b). The rate of decline in chilling hours is alarming with the annual total decreasing on average by 17.4 h per year at one location in Oman (Luedeling et al. 2009b). Ghrab et al. (2014) found that lack of chill frequency, affects the flowering and fruiting of commercial peach cultivars in warm regions. During warm-winter-years peach trees experienced flowering delay and an extended duration for flowering, increased bud abscission and double fruits, reduced fruit set and crop yields in the region of Mornag in northern Tunisia.

Other studies have estimated that climate change may have a significant impact on winter damage to fruit trees in eastern Canada (Rochette et al. 2004). Winkler et al. (2002) used climatic indices to estimate how climate change would affect commercial fruit production in the Great Lakes region. They concluded that climate change would reduce the frequency of freezing temperatures but would not have a clear impact on damage to plants by cold temperatures after critical growth stages are reached (Winkler et al. 2002). For the fruit tree species currently grown in eastern Canada that are well adapted to the current fall hardening conditions, climate change would further decrease the risks of damage due to inadequate fall hardening (Rochette et al. 2004). Climate change has also impacted apple cultivation in the Himalayas. In the Himalayas, the lack of early cold in December and January is understood to adversely affect the chilling requirements of apple trees (Vedwan and Rhoades 2001). Moreover, the Kullu Valley in the western Himalayas of India comprises the apple belt in the State of Himachal Pradesh and is famous throughout India for its apples. Over the past, the valley has witnessed a steady decline in apple production. In 1995, apple production amounted to just one-fourth that of the peak production year of 1988–1989 (Vedwan and Rhoades 2001). Climatic changes alter the pattern of blossoming that can affect bearing and, therefore, fruit yield in apple. The lack of early cold in December and January is understood to adversely affect the chilling requirements, which range from 700 to 1,200 h year⁻¹ in Kullu Valley in the western Himalayas of India (Vedwan and Rhoades 2001). Also, an April late cold can delay blossoming and reduce the pollination activity of bees that are the main pollinators of apples (Vedwan and Rhoades 2001), as well as pollen germination, which has been documented to be highly dependent on temperature (Ramírez and Davenport 2013). Other studies found decreasing trends of chilling units up to 2,400 m above msl from Bajaura in Kullu at 1,221 m above msl to Sarbo in Kinnaur at 2,400 m above msl in Himachal Pradesh, India (Singh et al. 2009). Increasing trends of chilling unit at the rate of

25.0 CUs per year was recorded at 2,700 m above msl. The increasing trends of chilling unit at 2,700 m above msl suggested that the area is becoming suitable for apple cultivation at higher altitudes (Singh et al. 2009). Furthermore, Jindal and Mankotia (2004) studied the influence of winter temperatures on effective chilling units, growing degree hours (GDH°C) requirements and physiological changes associated with the bud dormancy of ‘Starking Delicious’ apple in two locations, namely, Location A (ideal apple growing conditions with an altitude of 2,286 m above msl) and location B (marginal apple growing conditions with an altitude of 1,375 m above msl). These investigators found that chilling unit requirements for location A and B were 1,208 and 1,130 h, respectively. Whereas, the GDH°C requirements from dormancy to full bloom for the respective locations were 8,893 and 9,376 h (Jindal and Mankotia 2004). It was observed that with the increase in chilling exposure, the days required for bud break were reduced. Biochemical attributes in the shoots immediately after chilling treatments and after 15 days exposure to growing temperature (18 ± 2 °C) were also estimated (Jindal and Mankotia 2004). Other aspects such as inadequate pollinator proportion, reduction in natural population of pollinating agents, inadequate winter chilling, occurrence of spring frosts, hails and gales, nutrient deficiencies and droughts are the main factors leading to poor fruit setting in apples in the North-Western Himalayas of India (Gautam et al. 2004; Das et al. 2011). More research on fruit tree chilling requirements and climate change are needed in the Himalayan region.

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Chapter 10

Precipitation

Few studies have demonstrated the possible role of changes in precipitation and associated soil moisture to driving fruit tree phenophases (Grab and Craparo 2011). These authors noted that rainfall and temperature operate synergistically to influence mean full bloom dates for apples and pears in the southwestern Cape. Ultimately, the long-term temperature shifts in apple and pear tree phenological stages in the southwestern Cape region, South Africa may be attributed to the combined impacts of progressive regional warming and reduced winter/early spring precipitation, and/or associated longer dry spells during this season, which also impacts on ground water availability to plants. Precipitation contributes to earlier or later phenology in several places (Sparks and Carey 1995; Miller-Rushing and Primack 2008; Grab and Craparo 2011).

Prolonged rainy and heavily overcast conditions delay or stop mango flowering in the tropics (Ramírez et al. 2010a). Experiments conducted during rainy and overcast days showed that floral initiation was stopped or delayed until sunny conditions returned and flowering resumed in tropical Colombia (Ramírez and Davenport 2011 unpublished results). Similarly, Carabao and the Australian cultivar, R2E2, exposed to continuously rainy weather that extended through the resting period and beyond were not conducive to floral induction in the Philippines. However, once sunny conditions returned, trees began to flower (Davenport personal observation). Thus, continuous cloudiness derived from El Nino or la Nina (in either case) events can interfere with tree responses (Ramírez and Davenport 2012b). Mango flowering and vegetative flushes typically occur after the onset of each rainy season in La Mesa region, Colombia (Ramírez and Davenport 2010; Ramírez et al. 2010a, b). These events result in two harvest seasons per year occurring 3–4 months after each rainy season. About half the stems on each tree produce reproductive shoots in one season while the remaining stems initiate vegetative shoots. The pattern is reversed in the following rainy season with those stems that were reproductive in the previous season then initiating vegetative shoots and vice versa (Ramírez and Davenport 2010; Ramírez et al. 2010a). However, lately (2011–2013), all phenological stages occur during all months of the year due

to the constant overcast and rainy conditions and few sunny intervals. Under such conditions, trees have been observed as highly asynchronous having all stages (resting buds, vegetative, reproductive and fruit stages) (Ramírez unpublished results) (Fig. 2.1). Thus, mango fruits can be harvested on a round the year basis. Growers are concerned because picked fruits are fewer when compared to two floral and fruit seasons on a yearly basis (Ramírez and Davenport 2012a, b). This can also lead to a complete shift in the management practices, especially post-harvest technologies and marketing of this crop.

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Chapter 11

Ecophysiological Adaptations and Climate Change

Tropical plants have developed a number of ecophysiological adaptations for thriving at high elevations. These include restriction of root growth, shoot growth decline, high leaf pubescence, high leaf thickness and purple color anthocyanin rich leaves (Fischer 2000). Additionally, fruit trees such as Lulo (*Solanum quitoense*) tend to branch excessively when grown above their elevation range between 1,600 and 2,450 m in the Colombian Andes (Erazo 1991; Fischer 2000; Fischer et al. 2012). This species synthesizes more purple-colored anthocyanins in leaves, shoots and flowers when grown above 2,400 m (Erazo 1991). Most ecophysiological adaptations developed by fruit trees that live at high elevations in the tropics have been developed over the course of evolution. However, non-native or introduced fruit trees are known to adapt to high tropical elevations. This is the case of apples, which have adapted to chilling requirements at high elevations in many parts of the world (Ramírez and Davenport 2013). Other fruits grown in the tropics include peaches, pears, and plums (Ramírez and Kallarackal 2014). Exceptions to the requirement for chilling occur in some regions of the tropics, as in Indonesia, where defoliation soon after harvest induces bud break, resulting in two crops a year (Edwards and Notodimedjo 1987). Climatic conditions are ideal for fruit production in tropical environments (Ramírez and Kallarackal 2014). Tropical highlands have less temperature fluctuation than temperate conditions. Winter rain periods are interrupted by dry periods in the tropics. Many tropical countries have only one rainy season and other countries have two periods that are ideal for cropping apple, peaches and pears (Ramírez and Kallarackal 2014). In contrast to tropical conditions, temperate and subtropical fruit trees have developed chilling requirements and ecophysiological adaptations. Climate change may also affect the roots of fruit trees. Roots are less cold tolerant than aerial parts (Rochette et al. 2004). For example, the minimum survival temperature of roots ranges between -12 and -16 °C for trees and between -8 and -13 °C for dwarfing rootstocks (Quamme 1990; Quamme and Brownlee 1997; Rochette et al. 2004).

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Chapter 12

Biodiversity Implications and the Spread of Diseases

Reduction in fruit tree diversity in both agricultural and forest (native or endemic) vegetation are likely to occur as a long-term consequence of global warming. Temperate fruit trees are likely to be more affected by climate change than trees in the subtropics and tropics; however, among temperate fruit trees, cultivars might be less or more adapted to changing climatic conditions. Many indigenous tropical and temperate fruits have still remained underexploited due to the lack of awareness of their potential, market demand and low and erratic bearing in many cases (Malik et al. 2010). These species have multipurpose uses as fruits, vegetables and also have therapeutic and medicinal properties. Genetic resources of fruits are facing a serious threat of extinction due to climate change, large-scale urbanization and developmental projects (Malik et al. 2010). Tropical fruit trees may respond to climate change through phenotypic plasticity, adaptive evolution, migration to suitable sites or extinction (Sthapit et al. 2012). Moreover, selection of appropriate rootstocks in various fruit crops, e.g., mango and guava to suit the changed climatic conditions could be one of the solutions to temperature change (Sthapit et al. 2012).

Pests and diseases are also a major concern under global warming conditions. As a consequence of current and projected climate change in temperate regions of Europe, agricultural pests and diseases are expected to occur more frequently and possibly extend to previously unaffected regions (Hirschi et al. 2012). According to Hirschi et al. (2012), the codling moth (*Cydia pomonella*) and fire blight (*Erwinia amylovora*) are two major pests and disease threats to apple, one of the most important commercial and rural crops across Europe. Their results based on models for the codling moth indicate a shift in the occurrence and duration of life phases relevant for pest control. In southern Switzerland, a 3rd generation per season occurs only very rarely under today's climate conditions but is projected to become normal in the 2045–2074 time period. While the potential risk for a 3rd generation is also significantly increasing in northern Switzerland (for most stations from roughly 1 % on average today to over 60 % in the future for the median climate change signal of the multi-model projections), the actual risk will critically depend on the pace of the adaptation of the codling moth with respect to the critical

photoperiod (Hirschi et al. 2012). The negative effects of climate change are already evident for many of the 25 million coffee farmers across the tropics and the 90 billion dollar (US) coffee industry (Jaramillo et al. 2011). According to a recent study by Jaramillo et al. (2011), the most important pest of coffee worldwide, the coffee berry borer, *Hypothenemus hampei* (Coleoptera: Curculionidae: Scolytinae), has benefited from the temperature increase in East Africa. This is evidenced by increased damage to coffee crops and distribution range expansion. Furthermore, Jaramillo et al. (2009) had predicted that a 1 °C increase would lead to a considerably faster development, higher number of generations per fruiting season and a shift in the geographical range for *H. hampei*. Sthapit et al. (2012) reported that high temperatures coupled with high rainfall and humidity help in building up ideal conditions for the growth of a number of disease pathogens. For example, the powdery mildew disease in mango caused by *Oidium mangiferae* Berthet is a sporadic but serious disease of mango inflorescence that can cause up to 80–90 % losses of the crop in extreme cases. In mango and guava, it has been observed that the incidence of fruit fly is much less at higher temperature regimes (Sthapit et al. 2012). This was evidenced by the increased rate of development of fruit flies with increasing temperatures from 20 to 25 °C in mango fruit (Kumar et al. 2010).

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Chapter 13

Conclusion

Investigations on the impact of eCO₂ on fruit tree crops are comparatively very few in the literature, which limits the conclusions that can be drawn from such studies. However, available studies indicate that there is certainly an increase in vegetative and reproductive biomass due to higher CO₂ as also observed in forest trees. An interesting point is that some of the constituents such as vitamins have shown increase due to eCO₂. Down regulation of photosynthesis is possible in some of the species. Genetic manipulation to enhance the specificity of Rubisco for CO₂ relative to O₂ and to increase the catalytic rate of Rubisco in crop plants would increase potential yield, thereby increasing input-use efficiency of cropping systems as a whole. Nitrogen use efficiency is another important aspect to be investigated in fruit trees in a future climate change scenario.

Phenological observations in the temperate regions have shown that the bud break, flowering and fruiting in most fruit trees have advanced by several days. However, very few observations are available with regard to yield increase or decrease. In the subtropics, most studies have indicated advancement of flowering time in fruit trees. In the tropics there are very few studies on phenology in relation to climate change. From the available data it can be concluded that a longer period of drought is sometimes helpful in the flowering of some species provided they are drought resistant. Available data also indicate that it is necessary to develop phenological models in order to estimate the impact of climate change on plant development in different regions of the world.

An important constraint due to climate change is the reduction in winter chill especially in the temperate and subtropics. Most fruit crops require a definite number of chilling hours for proper flowering and fruiting. Available studies show that there has been considerable reduction in the past for the winter chilling hours. If this trend is going to continue (which probably will), then, many crops would be under serious threat as far as productivity is concerned, by the middle of this

century. This would offset the benefits of CO₂ fertilization which has been noticed in some of the species studied.

Species that are dependent on photoperiodic response to initiate their dormancy are more exposed to damage by the fall and early winter frosts. Changes in precipitation events can also lead to reduction in the yield of several fruit trees in all regions especially in the tropics. Many species will not flower properly if prolonged dry period is not available. Other aspects such as inadequate pollinator function, reduction in natural population of pollinating agents, inadequate winter chilling, occurrence of spring frosts, hails and gales, nutrient deficiencies, droughts, etc. can lead to poor fruit setting in several fruit trees.

Adaptation to climate change will require different strategies. South American farmers adapt to climate by changing crops (Seo and Mendelsohn 2008). Switching to other fruit species or varieties better suited to the changed climate would be an effective option, but it requires them large investments of time and space for planting young trees and their efforts for acquiring production technologies (Fujisawa and Kobayashi 2011). Inclusion of low chilling requirements as an explicit target in breeding programs is likely to produce cultivars that will remain suitable in a warmer future (Luedeling and Brown 2011). For most species, cultivars with a wide range of chilling requirements are available, providing some genetic potential for adaptation and further breeding to reduce chilling requirements (Luedeling et al. 2009). The future of the fruit tree crops in the different climate change scenario will depend on the different type of adaptations to be followed.

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