12 Impact of Climate Change on Potato

Bir Pal Singh, Vijay Kumar Dua, Panamanna Mahadevan Govindakrishnan, and Sanjeev Sharma

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.

B.P. Singh • V.K. Dua (✉)
P.M. Govindakrishnan • S. Sharma
Central Potato Research Institute,
171 001 Shimla, HP, India
e-mail: vkdua65@yahoo.co.in

H.P. Singh et al. (eds.), *Climate-Resilient Horticulture: Adaptation and Mitigation Strategies*,
DOI 10.1007/978-81-322-0974-4_12, © Springer India 2013

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

Atmospheric CO_2 conc. (ppm)	Rise in temperature (°C) 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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