Modern Trends in Microbial Biodiversity of Natural Ecosystem

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Preface

The microbe means an organism that is so small that normally cannot be seen without aid of a microscope. Microbial biodiversity includes Prokaryotes and Eukaryotes *viz.*, bacteria, fungi and viruses. They live in a wide variety of habitats. Microbes are essential to life they use to produce food as well as industrial compounds and they cause many diseases of plants and animals and are responsible for food spoilage. Modern trends are being appropriately used resulted into our knowledge of understanding diverse interactions of host with pathogens, mechanisms of disease development, host defend responses against the invading pathogens and identification of pathogens, specifically bacteria and viruses. Utilization of resistance genes in crops are also based on diversity analysis of the pathogen population in specific localities. "Modern Trends in Microbial Biodiversity of Natural Ecosystem" covering over 33 chapters is a comprehensive compilation of all those issues related to ecological, morphological, pathogenic and molecular diversity in phytopathogens, impact of environmental factors on fungal diversity in crop fields, utilization of microbial diversity for selection of efficient strains of entomopathogenic fungi, prospects of microbial diversity for seeds protection at storage, diversity analysis of mushrooms for nutritional and medicinal properties, diversity and potentiality of Actinomycetes for biological control, exploitation of soil microbial diversity for disease suppression, crop production and sustainable agriculture, utilization of molecular techniques for exploring microbial diversity, which are useful for undergraduate and post graduate students, research scholars, scientists working in the areas of Agriculture, Botany, Microbiology and Plant Pathology. We acknowledge our sincere thanks to the authors contributed the chapters.

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Contents

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Chapter 7

Climate Change and Plant Diseases: Changing Responses of Plant Pathogenic Microbes

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Since two decade back the topic of climate change and its potential impacts have consistently remained in the headlines of the scientific and popular press. This has been due to the mounting evidences for greenhouse gas induced changes in global and regional climate. Climate change represents one of the biggest scientific and political challenges of the 21st century. The greenhouse gas concentrations in the atmosphere are being altered by human activities thus causing global climate change. These activities have been intensified worldwide after the industrial revolution at the end of the 18th century result from the use of natural resources such as fossil fuel burning, deforestation and other land use changes. The atmospheric concentration of carbon dioxide (CO_2) has reached levels significantly higher than in the last 650 thousand years (Siegenthaler *et al.*, 2005). Since 2000, the growth rate of CO_2 concentration is increasing more rapidly than the previous decades (Canadell *et al.*, 2007). Similar trends have been observed for methane (CH_4), nitrous oxide (N_2O) and other green house gases (Spahni *et al.,* 2005; IPCC, 2007). Consequently, several changes in the climate have been recorded. The average global surface temperature has increased by 0.2°C per decade in the past 30 years (Hansen *et al.,* 2006). Alterations in the water cycle have also been observed. Changes will probably continue to happen even if greenhouse gas concentrations stabilize, due to the system's thermal inertia and to the long period necessary for returning to a lower equilibrium (IPCC, 2007).

The Intergovernmental Panel on Climate Change (IPCC), which was jointly established by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) in 1988, has responsibility for assessing information relevant to climate change and summarizing this information for policy makers and the public. The reports of IPCC (2001 and 2007) are major landmarks in the global change history in that these reports provide strong evidences that human induced climate changes are already a reality. For example the instrumental record shows that global mean surface temperature has increased by 0.6±0.2 during 20th century, the rate of temperature increase observed during the past 25 years is unprecedented during the last millennium. The global climate is predicted to change drastically over the next century and various parameters will be affected in this changing environment (Houghton *et al.,* 2001). This is the case for atmospheric CO_2 concentrations that increase continuously (IPCC, 2007). Additionally, global surface temperatures are predicted to increase between 1.8 and 3.6?C by the year 2100, driven by increased atmospheric CO_2 levels derived from natural and / or anthropogenic sources (IPCC, 2007; Compant *et al.,* 2010).

Although there is uncertainty surrounding the projection of future warming and other changes in climate, since 1990, when the first IPCC report was published, actual increases in the global temperature per decade have been within the range of projected increase of between 0.15 and 0.3?C per decade (Chakraborty *et al.,* 2008). The fourth IPCC assessment report projects a 0.2?C warming per decade for the next two decades for a range of IPCC emission scenarios originally outlined in IPCC special report (2000). Other changes in climate include rising sea level, shrinking of glaciers and increased rainfall in the middle and high latitudes of the Northern Hemisphere but a decrease over the sub-tropics. The global atmospheric CO_2 concentration has increased from about 280 ppm since the pre-industrial times (till 1750) to 379 ppm in 2005. This concentration exceeds the 180–300 ppm range observed from air pockets trapped within ice cores for over the last 650,000 years. Atmospheric concentration of other greenhouse gases including N_2O and CH_4 has also increased since pre-industrial times. The combined radiative forcing resulting from increases in greenhouse gases has led to a warming of the globe. For example, CO_2 radiative forcing has increased by 20 per cent from 1995 to 2005 (IPCC, 2007).

In a comprehensive view, global change encompasses all changes in climate, land, oceans, atmospheric composition and chemistry, and ecological systems that influence the global environment. The interactions between atmosphere, hydrosphere, cryosphere and biosphere as driven by solar radiation make our earth's climate. A part of the radiation reaching the earth is absorbed to heat up the earth's surface and some is radiated back to space. The oceans, covering over 70 per cent of the earth's surface, absorb solar energy; while snow and ice reflect 60–90 per cent of the solar energy. The reflected radiation is trapped by radiatively active water vapour, CO_2, CH_4, N_2O and O_3 in the atmosphere, acting like the glass of a greenhouse that warms the earth's surface, a natural phenomenon known as "green house effect". Based on a range of emission scenarios for greenhouse gases and aerosol precursors, global mean temperature is projected to rise between 0.9 and 3.5?C by 2100, but the actual decadal changes would include considerable variability. The longevity and radiative efficiency of these greenhouse gases determine their global-warming potential. Human activities are increasingly influencing the atmosphere, oceans, cryosphere and the terrestrial and marine biospheres, which together constitute the global climate system. Increased emissions of CO_2 and other radiatively active gases from industrial and agricultural development are changing the atmospheric composition. There is a strong interactive link between the large-scale clearing of forests in the humid tropics for logging and intensive agriculture, which alters global carbon balance and climate (IPCC, 1996; Chakraborty *et al.*, 2000). Global change, including a changing climate, is one of the most critical issues facing our future today as terrestrial and aquatic ecosystems which sustain life on earth are being increasingly affected by it. While the global population continues to rise, productive land resource, necessary for food production, shrinks. Uncertainties of climate change only magnify the challenge of increasing agricultural production to feed the ever increasing / expanding population. Climates continually change and due to climate change recent accelerated warming affect many biological systems (IPCC, 2007). The effects on the geographic distributions of pests and pathogens (Woods *et al.*, 2005; Admassu *et al.*, 2008; Elphinstone and Toth, 2008; Kudela, 2009), with potentially serious implications for food security is one of the most important issues (Newton *et al.*, 2010). However, cropping systems will also change in response to climate, with consequent impacts on their interactions with pests and pathogens.

The importance of the environment on the development of plant diseases has been known for over two thousand years. Theophrastus (370-286 B.C.) observed that cereals cultivated in higher altitude regions exposed to the wind had lower disease incidence than cereals cultivated in lower altitude areas. It is an established fact that the environment can potentially influence host plant growth and susceptibility, pathogen survival, reproduction, dispersal and activity as well as plant-microbe interaction or host- pathogen interaction (Garrett *et al.*, 2006). The classic disease triangle establishes the conditions for disease development, *i.e.*, the interaction of a susceptible host, a virulent pathogen and a favourable environment. This relationship is evidenced in the definition of plant disease itself (Gaumann, 1950). The classic disease triangle recognizes the role of physical environment in plant disease as no virulent pathogen can induce disease on a highly susceptible host if weather conditions are not favourable. Weather influences all stages of host and pathogen life cycles as well as the development of disease. Relationships between weather and disease are routinely used for forecasting and managing epidemics, and disease severity over a number of years can fluctuate according to climatic variation (Coakley, 1979; Scherm and Yang, 1995).

Plant pathogens are ubiquitous in natural and managed systems. They are among the first to demonstrate the effects of climate change due to the numerous populations, ease of reproduction and dispersal, and short time between generations. Therefore, they constitute a fundamental group of biological indicators that needs to be evaluated regarding climate change impacts. The plant pathogen groups include fungi, prokaryotes (bacteria and mycoplasmas), oomycetes, viruses and viroids, nematodes, parasitic plants and protozoa. The very different life histories of this diverse group of organisms and their different interactions with host plants produce a wide range of responses to environmental and climatic drivers. For example, viruses may be present in hosts while symptom expression is dependent on temperature thus, even the difficulty of detection of these pathogens varies with climate. Fungal pathogens are often strongly dependent on humidity or dew for plant infection (Huber and Gillespie, 1992), so changes in these environmental factors are likely to shift disease risk. Pathogen populations may explode when weather conditions are favourable for disease development. Despite the threat posed by climate change to plant protection in the near future, there are few reports about this subject (Newton *et al.*, 2010).

Effect of Climate Change on Plants

The geographical distribution and growth of plant species are influenced due to climate change around the world. These impacts on plants vary depending upon the species involved and their growth patterns *e.g.* annual vs perennials, type of plants *e.g.* agricultural or domestic plant vs natural vegetation, their competition ability, migration and ability of recovery from different stresses. The options for managing annual crops from the effects of climate changes are more because there is always opportunity to change annually the location, cultivar, time of sowing or planting and acerage of the crops. The direct effects of climate change on individual plants and plant communities may occur in the absence of pathogens, but may also bring about changes in plants that will affect their interactions with pathogens. Changes in plant architecture may affect microclimate and thus risks of infection (Burdon, 1987). In general, increased plant density will tend to increase leaf surface wetness and leaf surface wetness duration and so make infection by foliar pathogens more likely (Huber and Gillespie, 1992). Abiotic stress such as heat and drought may contribute to plant susceptibility to pathogens or it may induce general defense pathways which increase resistance (Garrett *et al.*, 2006).

Elevated CO_2 levels tend to result in changed plant structure. At multiple scales, plant organs may increase in size: Increased leaf area, increased leaf thickness, higher numbers of leaves, higher total leaf area per plant, and stems and branches with greater diameter have been observed under elevated CO_2 (Pritchard *et al.*, 1999). Enhanced photosynthesis, increased water use efficiency and reduced damage from ozone are also reported under elevated CO_2 (Seem, 2004). Since many foliar pathogens benefit from denser plant growth and the resulting more humid microclimate (Burdon, 1987), there is the potential for these changes in plant architecture to increase infection rates. The effects of elevated temperature on plants vary greatly throughout the year. During colder season, warming may relieve plant stress, whereas during hotter parts of the year it may increase stress. When high-temperature stress is exacerbated, plant responses may be similar to those induced by water stress, with symptoms including wilting, leaf burn, leaf folding, and abscission, and physiological responses including changes in RNA metabolism and protein synthesis, enzymes, isoenzymes, and plant growth hormones (Garrett *et al.*, 2006). These changes will certainly affect susceptibility to pathogens, though the wide range of changes can make interactions difficult to predict. The potential effects of temperature on crop plants can be understood by the fact that rice yield decline upto 10 per cent for each 1?C increase in the minimum temperature during the dry season (Peng *et al.*, 2004). The elevated ozone enhance the susceptibility of plant to several foliar pathogens by changing structure of leaf surface by altering physical topography as well composition of surfaces, including the structure of epicuticular wax (Karnosky *et al.*, 2002). The Ozone exposure has been proposed to enhance susceptibility of plants to necrotrophic fungi, root-rot fungi, and bark beetles (Sandermann, 2000; Garrett *et al.*, 2006).

Impacts of Climate Change on Host-Pathogens System

Climate is most frequently the primary driving force for successful host-pathogen interactions and more is known about how climate affects disease development than how various atmospheric chemicals do. The early studies of air pollutants focussed on direct damage to the host, *i.e.*, the air pollutant behaving as the pathogen. With increased evidences for climate change, the emphasis of research has shifted from pollutants as pathogens to the effect of these climate change components on host, pathogen and host-pathogen interactions. Climate change and its elements affect the host, pathogen and their interactions both directly and indirectly and at different levels. For example, the direct effect of ozone on a mycorrhizal fungus results in an indirect effect on its host. Similarly environmental factors that influence insect vector activities or weed competition have indirect effects on the host and therefore host-

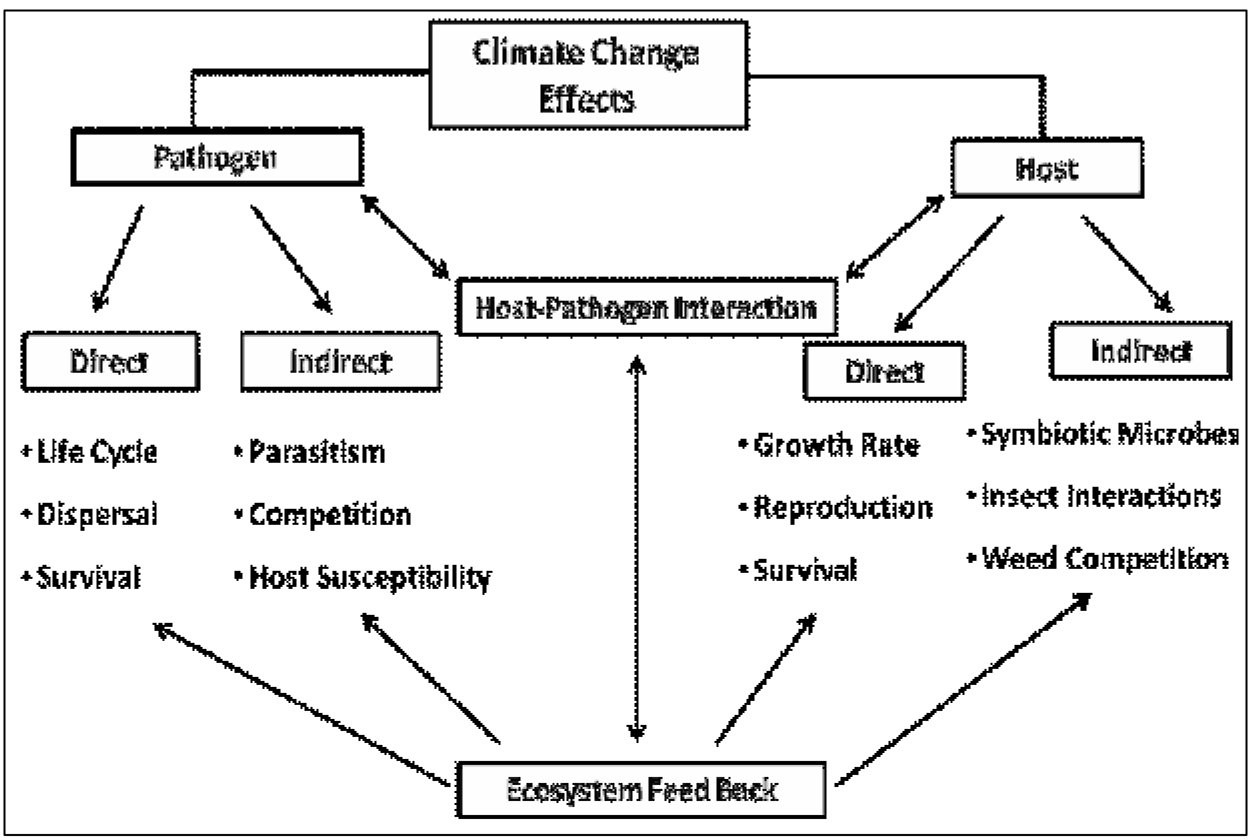

Figure 6.1: Conceptual Model of the Effects of Climate Change on Host, Pathogen and their Interaction

***Source*: Adapted from Coakley (1995) with slight modification**

pathogen interaction. Global climate change that increase or decrease biocontrol of a pathogen, or the competition among pathogens, indirectly affect the pathogens.

In case of direct effect of climate change elements on pathogens, it may influence its generation time, or its dispersal or survival. Equally as important as direct effect is the ecosystem feedback from the host-pathogen interaction. Interactions between different climate change factors may occur that enhance or inhibit their impact on the host or pathogen. Also, a particular climate change element may have a positive effect on one part of the disease triangle but a negative on another. For example elevated CO_2 may increase host growth, but also weed competition, increased temperature may increase evapotranspiration and increase water use or loss and ultimately results in water stress for the plants (Coakley, 1995). The range and severity of a plant diseases increased by global warming have also been reported (Evans *et al.*, 2008). Due to comprehensive impacts of climate changes on host-pathogens system more aggressive strains of pathogen with broad host range, such as *Rhizoctonia*, *Sclerotinia*, *Sclerotium* and other necrotrophic pathogens can migrate from agroecosystems to natural vegetation, and less aggressive pathogens from natural plant communities can start causing damage in monocultures of nearby regions. Regarding unspecialized necrotrophs, the range of hosts can be extended due to crop migration (Chakraborty *et al.*, 2000; Ghini *et al.*, 2008).

Effects of Climate Change and its Various Elements on Fungal Pathogens

Environmental conditions have a major influence on the survival, propagation and dispersal of fungal plant pathogens. The effects of the climate change are perhaps most obvious for fungal pathogens, which require suitable temperatures and minimum amounts of moisture to survive and reproduce and to initiate the infection process in plants. Most plant pathogens complete part of their life cycle on their host plants and the remaining part in the soil or on plant residues in the soil. Thus, temperature and moisture conditions in both air and soil are important for pathogen survival and development. The effects of various climate change elements are as discussed below:

Effect of Elevated CO_2

Increased CO_2 level can impact on the fungal pathogens in multiple ways. The disease severity can be enhanced or reduced under elevated CO_2. Elevated CO_2 levels tend to result in changed plant structure. At multiple scales, plant organs may increase in size: increased leaf area, increased leaf thickness, higher number of leaves, higher total leaf area per plant and stems and branches with greater diameter has been observed (Pritchard *et al.*, 1999). This results in a greater biomass production and microclimates may become more conducive for development of several fungal diseases *viz.*, rusts, mildews, leaf spots and blight diseases. As a consequence of increased plant growth under elevated CO_2, C: N ratio of litter increases which lead to slower decomposition rate. The decomposition of plant litter is important for nutrient cycling and in the saprophytic survival of many pathogens. Increased plant biomass, slower decomposition of litter and higher winter temperature could increase pathogen survival during over-wintering on crop residues and increase the amount of initial inoculum available for subsequent infection.

Regarding fungal pathogens, important alterations can occur as a consequence of an increase in CO_2 concentration. There can also be direct effects on pathogen growth; for example the enhanced growth of *Colletotrichum gloeosporioides* infecting *Stylosanthes scabra* has been reported at high CO_2 (Chakraborty and Datta, 2003). CO_2 can also affect pathogen fecundity which was shown to increase under elevated CO_2 levels leading to enhanced rates of pathogen evolution (Chakraborty and Datta, 2003). They reported that the aggressiveness increased for the resistant cultivar, but not for the susceptible cultivar. Similar results were reported by Osswald *et al.* (2006), while working with host-pathogen system of potato and *Phytophthora infestans.* These results are extremely important for the study of epidemiology of the disease demonstrating that the pathogen can adapt to a new environment. The incidence of rice plants naturally infected with sheath blight (*Rhizoctonia solani*) was generally higher at elevated CO_2 concentrations under high nitrogen levels, but this trend was not apparent for sheath blight severity (Chakraborty *et al.*, 2008). *Arabidopsis thaliana* was found more susceptible to *Erysiphe cichoracearum* under high CO_2 concentration, correlated with increased stomatal density and guard cell length, but there were inherent differences between ecotypes in this response (Lake and Wade, 2009; Newton *et al.*, 2010). In rice, enhanced susceptibility to *Magnaporthe oryzae* under elevated CO_2 was attributed to lower leaf silicon content (Kobayashi *et al.*, 2006; Newton *et al.*, 2010).

Effect of Temperature

Temperature is one of the most important climate change factors that influence the disease severity and establishment of infection by fungal pathogens. Both temperature and the length of exposure are important in determining the effect of climate change on disease severity. The higher temperature in a particular area may lead appearances of invasive alien species of fungal pathogens that can cause severe epidemic on important crops. Change in temperature will directly influence infection, reproduction, dispersal, and survival between seasons and other critical stages in the life cycle of a fungal pathogen. Higher temperature can modify host physiology and resistance (Garrett *et al.*, 2006) for example at higher temperature, lignification of cell walls increased in forage species and enhanced resistance to fungal pathogens. Impact would, therefore, depend on the nature of the host- pathogen interactions and mechanism of resistance. A rise in temperature above 20°C can inactivate temperature sensitive resistance to stem rust in oat cultivars. Increase in temperature with sufficient soil moisture may increase evapo-transpiration resulting in humid microclimate in crop canopy and may lead to incidence of diseases favoured under warm and humid condition. Some of the soil-borne diseases may increase at the rise of soil temperature (Compant *et al.*, 2010). Bergot *et al.* (2004) predicted the geographic range expansion of *Phytophthora cinnamomi* in Europe in response to increased temperatures that would allow for overwintering of this oomycete in new areas. Several workers suggested that under conditions of increased temperature due to global warming the survival and degree of root disease seems likely to be enhanced, while the host range of microorganisms might also be increased (Brasier and Scott, 1994; Brasier *et al.*, 1996; Garrett *et al.*, 2006; Compant *et al.*, 2010).

Effects of Elevated Levels of Atmospheric Pollutants (Ozone and Nitrous Oxide)

Ozone (O_3) is a secondary pollutant that is increasing downwind of major metropolitan areas around the world (IPCC, 2001; Vingarzan, 2004). It is a highly phytotoxic pollutant that decreases carbon assimilation of O_3-sensitive plants through direct effects on photosynthesis, leaf area and leaf area duration (Krupa *et al.,* 2000; Karnosky *et al.,* 2007). It has long been known that ozone can also alter plant responses to biotic diseases (Manning, 1975; Sandermann, 2000; Fuhrer, 2003; Ashmore *et al.,* 2006). Effects of O_3 on pathogen interactions are variable depending on the timing of the exposure to both plant and the pathogen, the O_3 concentration, the stage of plant development, predisposing factors and environmental conditions (Fuhrer, 2003). Elevated ozone concentrations can change the structure of leaf surfaces, altering the physical topography as well as the chemical composition of surfaces, including the structure of epicuticular wax (Karnosky *et al.,* 2002). These changes in leaf structure may alter leaf surface properties such as leaf wettability and the ability of leaves to retain solutes; all influencing the ability of pathogens to attach to leaf surfaces and infect (Karnosky *et al.,* 2002). Plants appear to be less sensitive to nitrous oxide; however, higher concentrations can cause water-soaked lesions, which soon turn brown. Ozone and nitrous oxide injury on plants in turn may add new problem to pathologists in diagnosis. Current climate change scenarios predict a further increase of tropospheric ozone, which is well known to inhibit plant photosynthesis and growth process. Ozone can also predispose plants to enhanced biotic attack, as proposed in particular for necrotrophic fungi, root rot fungi and black beetles (Sandermann, 2000; Garrett *et al.,* 2006). Several root pathogens show a preference for stressed trees, although the direct role of ozone in disease development is not always evident.

The occurrence of co-occurring elevated atmospheric CO_2 can also alter the O_3 disease interactions (von Tiedemann and Firsching, 2000; Plessl *et al.,* 2007). Thus, it is not surprising that O_3 biotic disease interactions have ranged from significant enhancement for diseases such as powdery mildew (*Erysiphe graminis*), leaf spot disease (*Septoria nodorum*) and spot blotch (*Bipolaris sorokiniana*) on wheat flag leaves exposed to O_3 (von Tiedemann *et al.,* 1991), tan spot fungus (*Pyrenophora tritici-repentis*) on wheat (Sah *et al.,* 1993) and other root diseases experiments (Fenn *et al.,* 1990; Pritsch *et al.,* 2005) to decreases or no impact with other diseases. The occurrence of mycorrhizal and non-mycorrhizal root-infecting fungi (Bonello *et al.,* 1993), powdery mildew (*Sphaerotheca fuliginea*) on cucumber (Khan and Khan, 1999), spot blotch on barley and fescue (Plazek *et al.,* 2001) and leaf rust (*Puccinia recondita*) on wheat (von Tiedemann and Firsching, 2000) have been shown to decrease with O_3. Finally, at least one study has shown no interaction of O_3 and pathogen occurrence in wheat (Pfleeger *et al.,* 1999).

Effect of Acid Rain

Acid rain is the result of human activities, primarily the combuston of fossil fuels (oils, coal and natural gas) and smelting of sulphide ores. These activities release large quantities of sulphur and nitrogen oxides in the atmosphere, which when in contact with atmospheric moisture are converted into two of the strongest acids known (sulphuric and nitric) and fall to the ground in the form of rain, snow and fog. The pH of acid rain over a large region of world ranges from 4.0 to 4.5 but the lowest rain pH values reported so far pH 1.5 in West Virginia and 1.7 in Los Angeles (Agrios, 2005). Most studies on the effect of acid rain were done with simulated acid rain since it is not easy to establish experiments under field conditions (Asai and Futai, 2005). Variable effects of acid rain on four different patho-systems: alfalfa leaf spot (ALS), peanut leaf spot (PLS), potato late blight (PLB), and soybean brown spot (SBS) have been observed by Campbell *et al*. (1988) during their two year's study.

Experiments conducted to determine the effect of acid rain on the initiation and development of plant diseases have shown that telia formation of *Cronartium fusiforme* rust of oak was same as at pH 6.0 under acid rain of pH 3.0, whereas similar nematode egg mass production was noticed in same host plant at acid rain of 3.2 pH as it was under rain of pH 6.0. However, a bacterial disease 'Halo blight' and rust disease of bean were some times more severe and other milder with acidic rain than with the pH 6.0 rain (Agrios, 2005).

Effect of Elevated Ultraviolet B

The effect of UV-B on the incidence and development of pathogen-induced diseases on crops is dependent upon the crop cultivar, age, pathogen inoculum level and the timing and duration of UV-B exposure (Krupa *et al.*, 2000). In some cases, a shift in one kind of atmospheric component may have a profound effect on another, for example the ozone hole thought to be caused by chlorofluoromethanes has led to an increase in UV-B radiation (Ashmore and Bell, 1991). The effect of UV-B radiation on fungal- host interactions is now an increasingly studied subject. One of the first studies about this subject was conducted by Luo *et al*. (1995). They carried out a risk analysis of rice blast epidemics and plant growth associated with climate change in several Asian countries due to the importance of this crop and to the losses related to this disease, caused by *Magnaporthe grisea*. Simulations were made to study the risk of blast epidemics under the effects of temperature change and enhanced UV-B radiation. The results demonstrated that changes in the amount of rainfall do not affect the occurrence of the epidemics since they have little effect on the leaf wetting period. In cool subtropical zones, higher temperatures caused increases in disease severity and in the area bellow the disease progress curve, because higher risk of epidemics occurs under higher temperatures. In humid tropical and humid warm subtropical zones, such as Southern China, Philippines and Thailand, the opposite effect was observed. Lower temperatures increased the risk of rice blast epidemics since the current temperatures in these regions are above favourable values for the occurrence of this disease. However, a larger area bellow the disease progress curve does not always result in lower rice yield, since the effect in plant growth also takes place. The effects of the increase in UV-B radiation were highly significant for the occurrence of epidemics.

Effect of Climate Change and its Elements of Bacterial Pathogens

At present about 400 bacterial plant pathogens are known (Kudela, 2009). Bacteria multiply with astonishing rapidity and their significance as pathogens originates primarily from the fact that they can produce tremendous numbers of cells in short period of time (Agrios, 2005). The climate change induced effects on geographic distribution of plant pathogenic bacteria have been reported (Kudela 2009). Due to climate change factors like climate warming and draught stress thermophillic bacteria can emerge potentially where as decrease in the cold tolerant species of these bacteria can be observed. Insect vector borne xylem limited bacteria can pose new emerging threat to agricultural crops in changing global climate, as these insect vectors can adjust effectively with the changing climate (Hamilton *et al.*, 2005). The consequences of climate change impacts on bacteria are as follows:

Emergence of Thermophillic (Heat-Loving) Bacteria

Temperature is undoubtedly one of the most important factors influencing the occurrence and development of many plant pathogenic bacteria. Climate model simulations using future emission scenarios of greenhouse gases and aerosols suggest an increase in global mean temperature between 1 and 3.5°C by the year 2100. Since, there is solid evidence that global warming is occurring and if such conditions continue, heat-loving plant pathogenic bacteria should be expected to increase. A common trait of these high-temperature bacteria is an optimum growth temperature of 32–36°C (most grow well up to 41°C) whereas most other plant pathogenic bacteria grow best at lower temperatures (Kudela, 2009). Among heat-loving plant pathogenic bacteria that have emerged as serious problem worldwide belong following bacterial plant pathogens: *Ralstonia solanacearum, Acidovorax avenae* subsp. *aveane,* and *Burkholderia glumea* (Schaad, 2008).

Why the increase in these heat-loving bacteria? The most likely explanation is the influence of global warming on the World’s climate. The evidence for global warming is quite broad, including, major shifts in recorded temperature and precipitation, melting glaciers and reduced snow cover, and more frequent and severe storms and droughts. Studies have shown global warming is caused primarily by heat-trapping greenhouse gas (GHG) emissions (IPCC, 2007). Industrial activity, from the burning of fossil fuels such as coal, oil, and gas, generates CO_2 and other gases which trap the sun’s rays in the atmosphere and enhance the natural “greenhouse effect” (Gore, 2006). Although automobiles and industry are considered the major contributors of GHG, the increase in air traffic is emerging as a major factor. “Concentrations of CO_2, the prime GHG, have increased 30 per cent during the past 100 years” (Fallon, 1997). These comprehensive impacts of climate change element favour the emergence of thermophillic bacteria.

Changes in the Spectrum of Pectolytic Bacteria

Some bacterial phytopathogens have strong pectolytic capacities that enable them to cause soft-rots (*i.e.*, tissue-macerating diseases and storage rots) in a wide variety of plants. They are economically important because of the crop loss they can cause both in the field and after harvest in transit and in storage (Perombelon, 1982; Starr, 1983; Schaad, 2008; Kudela, 2009). Among the species of pectolytic bacteria associated with crop loss, *Erwinia* spp. (also known as *Pectobacterium* spp.) and *Clostridium* are economically important in temperate area. In warmer climates species of the other genera may play an important role (*e.g.*, *Bacillus* spp., whose pathogenicity is often greater at high temperatures–Perombelon, 1982). Ecology of soft rot erwinia reviewed by Perombelon and Kelman (1980). Soft rot erwinia differ in temperature optima and requirements. Strains of *Erwinia carotovora* subsp. *carotovora* (*Ecc*) but not *Erwinia carotovora* subsp. *atroseptica* (*Eca*) will grow at 37°C and, whereas most strains of the former are inhibited at 39°C, those of *Erwinia chrysanthemi* (*Echr*) grow relatively well at > 39°C. These temperature characteristics are reflected in their host range as affected by geographical distribution (Kudela, 2009).

A Decrease in the Frequency of Occurrence of Cold Tolerant Pseudomonads and an Increase in more Thermophilic Xanthomonads Population

The most of plant pathogenic bacteria belong to the *Pseudomonas* genus or *Xanthomonas* genus (Kudela, 2009). In general, pseudomonads (namely *Pseudomonas syringae* group) and the most of xanthomonads produce necrotic lesions on foliage, stems, or fruit that develop into spots, streaks, or cankers. They affect plants worldwide, causing varying amounts of damage in crops of nearly every plant family (Starr, 1983). Minimal growth temperature of *Pseudomonas* spp. is 4–5°C, whereas it is 7–9°C in *Xanhomonas* spp. (Klement *et al.*, 1990) Therefore, cold tolerant pathogenic pseudomonads cause serious losses in cooler areas including Central Europe. In contrast to pseudomonads, xanthomonads are more commonly found in tropical and subtropical conditions. These comprehensive impacts of climate change elements mainly climate warming reduce the frequency of occurrence of cold tolerant pseudomonads and as a result of climate warming population of thermophillic xanthomonads will increase.

Increased Risk of Xylem-Limited Bacteria which Overwinter in Insect Vectors

Some plant pathogenic bacteria overwinter within bodies of their insect vectors. Insect transmission of plant pathogenic bacteria is usually non-specific. Examples of the specific transmission are xylem limited bacteria *Xylella fastidiosa* subsp. *fastidiosa* causing diseases in grape (Pierce's disease), alfalfa, maple and almond and *X. f.* subsp. *multiplex* causing diseases in peach (phony peach disease), plum, almond, elm *etc.* Causal agent, *Xylella fastidiosa*, is vectored by xylem sucking insects, such as sharphooters (subfamily Cicadellinae in the leaf-hopper family Cicadellidae) and spittlebug (*Philaenus spumarius*, family Cercopidae) found also in Europe. *P. spumarius* is associated with Pierce's disease of grapevine and almond leaf scorch, however, its relative threat as invasive vector is reported low in USA (Redak *et al.*, 2004). As these insect vectors can adjust effectively with the changing climate (Hamilton *et al.*, 2005), they can pose new emerging threat to agricultural crops due to their associated xylem limited bacteria in changing global climate.

Effect of Climate Change and its Elements on Viral Plant Pathogens

Most of the studies related to climate change and its impacts have been conducted on fungal plant pathogens. Only few studies have reported the response of plants infected with viral diseases to various climate change components. It has been observed that oats infected with *Barley yellow dwarf virus* (BYDV) showed three fold greater biomass accumulation to CO_2 enrichment than the healthy plant (Malmstrom and Field, 1997). Tobacco plants grown at elevated CO_2 concentrations showed a markedly decreased spread of virus. It appears that CO_2 rise in the air may have some positive effects, which may likely offset the negative effects of virus infection. Gioria *et al*. (2008) during their prediction of important tomato diseases and influence on climate change showed that climate change will not alter the importance of tomato mosaic disease caused by *tomato mosaic virus* (ToMV). In contrast authors considered that the importance of *tomato spotted wilt virus* (TSWV), *tomato chloratic spot virus* (TCSV), *groundnut ring spot virus* (GRSV), *Chrysanthemum stem necrosis virus* (CSNV) and *yellow leaf curl virus* (Geminivirus) will be increased due to climate change. Because of the elevated temperature soil water content is expected to decrease (Compant *et al.,* 2010) which leads to draught condition. Drought stress and disease stress may have additive effects on plants, as observed for infection by *Beet yellows virus* (Clover *et al.,* 1999), and *Maize dwarf mosaic virus* (Olson *et al.,* 1990).

Effect of Climate Change on Nematode

Most of the plant pathogenic nematodes spend part of their lives in soil and therefore soil is the source of primary inoculum. Life cycle of a nematode can be completed within 2-4 weeks under favourable environmental conditions. Temperature is the most important factor influencing the population dynamics of plant pathogenic nematodes. The development of plant parasitic nematodes is slower with cooler soil temperatures. Warmer soil temperatures are expected to accelerate nematode development, perhaps resulting in additional generations per season. While drier temperatures are expected to increase symptoms of water stress in plants infected with nematodes such as soybean cyst nematode. Overwintering of nematodes is not expected to be significantly affected by changes in climate, although for some such as the soybean cyst nematode, egg viability may be reduced in mild winters. The effect of climate change on distribution of *Meloidogyne incognita* in coffee crop was evaluated by Ghini *et al*. (2008). The distribution map indicated that there could be an increase in infestation of this nematode due to the higher number of generations per month as compared to previous years. Similar results are reported earlier by Carter *et al*. (1996) during studies on distribution of the potato cyst nematode (*Globodera rostochiensis*) and Boag *et al*. (1991) also obtained similar results for the plant-parasitic nematodes *Xiphinema* and *Longidorus* during the study of the geographical distribution of these virus-vector nematodes.

Effects of Climate Change on Insect Vector

Insects are key factors in the transmission of several plant diseases. Besides numerous viral diseases they are potential vectors of other disease caused by several plant pathogens *viz.*, fungi, bacteria, phytoplasma, viriods etc. Hence, in these pathosystems, the effect of climate on vector survival, reproduction and efficiency of pathogen transmission is directly linked to disease development. Insects are cold-blooded organisms. The temperature of their body is approximately is same that of the environment. Therefore, temperature is probably the single most environmental factor influencing each and every sphere of their life cycle *viz.* insect behaviour, distribution, development, survival and reproduction. Insect life stage predictions are most often calculated using accumulated degree days from a base temperature and biofix point. Some researchers believe that the effect of temperature on insects largely overwhelms the effect of other environmental factors (Bale *et al.*, 2002). It has been estimated that with a 2?C temperature increase, insect might experience one to five life cycles per season (Yamamura and Kiritani, 1998). Several other researchers have found that moisture and CO_2 effects on insects can be potentially important considerations in a global climate change setting (Coviella and Trumble, 1999; Hunter, 2001; Hamilton *et al.*, 2005). Thus, the effect of climate change on vector-borne plant diseases can be complex and it is difficult to generalize potential future impacts due to climate change.

Climate Change and Alien Invasive Species

The alien invasive species are both a cause and a consequence of global change (Scherm and Coakley, 2003). Being one of the major contributors to global change, invasive non-indigenous organisms are already having serious adverse impacts on our ecosystem (Scherm and Coakley, 2003; Admassu *et al.*, 2008). Similar to other global change drivers such as climate warming and changes in land-use patterns, the magnitude of the problem has increased considerably during the second half of the 20^{th} century mainly due to upsurge in global travel and trade during the past 25 years. At the same time, stressor such as rising temperatures and habitat degradation may predispose ecosystems to biological invasions and these invasions thus become a consequence of other global changes. According to an estimation 239 species of non-indigenous plant pathogens had become established by the early 1990s in United States (National Research Council, 2002). Most of these, including highly devastating pathogens such as Wheat rust (*Puccinia* spp.), White pine blister rust (*Cronatium ribicola*), chestnut blight (*Cryphonectria parasitica*) and Dutch elm disease (*Ophiostoma ulmi*) were introduced before the mid-1900s (Yarwood, 1983). Although many introductions of novel plant pathogens have already occurred in different parts of the world, climate change may facilitate their further establishment and spread. A new race of *Puccinia graminis* f. sp. *tritici*, Ug99 has been reported from Uganda in 1999 and since then it is causing severe losses to wheat production in many countries where it had not been reported earlier (Admassu *et al.*, 2008). In some cases, however, there is the possibility that the risk of the introduction of some plant pathogens may decrease due to changes in precipitation patterns predicted under climate change. However, the pathogen propagule pressure due to modern trade within and between continents, with plants moved around the world in both shipping and air networks, makes it possible that new plant health problems will arise with their potential threat.

Climate Change and Plant Disease Management

Diseases are responsible for losses of at least 10 per cent of global food production, representing a severe threat to food security (Strange and Scott, 2005). Agrios (2005) estimated that annual losses by disease cost US$ 220 billion. Besides direct losses, the methods for disease control especially the chemical methods can result in environmental contamination and in residual chemicals in food, in addition to social and economic problems. The close relationship between the environment and diseases suggests that climate change will cause modifications in the current phytosanitary scenario. The impacts can be positive, negative or neutral, since there can be a decrease, an increase or no effect on the different pathosystems, in each region. The analysis of the potential impacts of climate change on plant diseases is essential for the adoption of effective management practices including development of resistant cultivars in order to avoid more serious crop losses (Chakraborty and Pangga, 2004; Ghini, 2005; Chakraborty *et al.*, 2008).

The well-known dependence of plant diseases on weather has long been exploited for predicting epidemics and to time applications of control measures for tactical disease management. Disease management strategies depend on climate conditions. Climate change will cause alterations in the disease geographical and temporal distributions and consequently the control methods will have to be adapted to this new reality. Changes in temperature and precipitation can alter fungicide residue dynamics in the foliage and the degradation of products can be modified. Alterations in plant morphology or physiology, resulting from growth in a CO_2-enriched atmosphere or from different temperature and precipitation conditions, can affect the penetration, translocation and mode of action of systemic fungicides. Besides, these changes in plant growth can alter the period of higher susceptibility to pathogens which can determine a new fungicide application calendar (Coakley, 1995; Chakraborty and Pangga, 2004; Pritchard and Amthor, 2005). The per acre pesticide usage average cost for corn, cotton, potatoes, soybeans and wheat were found to increase as precipitation increases. Similarly, the pesticide usage average cost for corn, cotton, soybean and potatoes also increase as temperature increases, while the pesticide usage cost for wheat decreases (Ghini *et al.*, 2008).

The physiological changes in host plants may result in higher disease resistance under climate change scenarios, host resistance to disease may overcome more quickly by more rapid disease cycles, resulting in a greater chance of pathogens evolving to overcome host plant resistance. Fungicide and bactericide efficacy may change with increased CO_2, moisture, and temperature. The more frequent rainfall events predicted by climate change models could result in farmers finding it difficult to keep residues of contact fungicides on plants, triggering more frequent applications. Systemic fungicides could be affected negatively by physiological changes that slow uptake rates, such as smaller stomatal opening or thicker epicuticular waxes in crop plants grown under higher temperatures. These same fungicides could be affected positively by increased plant metabolic rates that could increase fungicide uptake. Genetic variation in pathogen populations often makes plant disease management more complicated when pathogens overcome host disease resistance (Strange and Scott, 2005). Pathogen species may quickly develop resistance to pesticides or adapt to overcome plant disease resistance, and may also adapt to environmental changes, where the rate of adaptation depends on the type of pathogen (McDonald and Linde, 2002). The potentially rapid onset of disease makes it difficult to anticipate the best timing of management measures, especially in areas with high levels of interannual variability in climatic conditions.

There is relatively less information on the impacts of climate change on plant disease biological control. The few results obtained focus on climate change impacts on the composition and dynamics of the microbial community of the phyllosphere and the soil, which can be very important for plant health (Ghini *et al.*, 2008; Compant *et al.,* 2010). The prediction of the effects of climate change on plant disease biological control is complex and currently based on indirect observations. And one of the major problems with applications of biological control for plant disease management in the field has been the vulnerability of biocontrol agent populations to environmental variation and environmental extremes (Grevstad, 1999; Wong *et al.,* 2002; Garrett *et al.,* 2006; Compant *et al.,* 2010). If appropriate temperature and moisture are not consistently available, biocontrol agent populations may reach densities that are too small to have important effects, and may not recover as rapidly as pathogen populations when conducive conditions recur (Gibson *et al.,* 1999; Garrett *et al.,* 2006). The increased efficiency of *Chlonostachys rosea*, an important biological control agent of *Botrytis* spp. and other pathogens, and *Metarrhizium anisopliae,* one of the most important entomopathogens for insect pest control, has been reported (Rezacova *et al.,* 2005) strongly associated with the cover crop in a high CO_2 concentration environment. The authors suggested the abundance of these fungi species can indicate an increase in the soil suppressiveness to phytopathogenic fungi and other pests.

Climate Change and International Collaboration

The speed of climate change and unpredictability of its characteristics are of great concern to biologists as well as social activists. The number of studies on the effects of climate change has escalated in the last 10 years due the increase availability of funding to examine climate change related questions. Numerous international and interagency efforts have been undertaken. One example is the International Geosphere-Biosphere Programme: A study of Global Change of the International Council of Scientific Unions; this group has produced an operational plan for a study of global change and terrestrial ecosystem. International, interdisciplinary collaboration on aspects of global change affecting plant disease in natural and managed system will play more important role in years ahead (Scherm and Coakley, 2003). This may range from small, specialist research networks with a relatively narrow focus to broad umbrella projects that encompass multiple science and policy themes and involve numerous intergovernmental agencies as well as national and international donors. A good example of this type is the potato late blight simulation network established jointly by Global Initiative for Late Blight (GILB) and Global Change and Terrestrial Ecosystem (GCTE) project. The overall goal of this particular group is to develop an operational platform for simulating the effects of selected global change drivers on late blight intensity and potato yields on global scale. The

Global Environmental Change and Food System Project (GECAFS) represents a recent example of a broader umbrella network that aims to determine strategies to cope with the impact of global change on food provision systems and to analyse the environmental and socio-economic consequences of adoption. This project was launched officially in 2002; the project builds upon and adds value to the work of the International Geosphere-Biosphere Programme (IGBP), the international Human Dimensions Programme on Global Environmental Change (IHDP), and the World Climate Research Programme (WCRP). GECAFS includes three science theme and concentrate on (1) vulnerability and impacts of global change on food provision, (2) adaptation to global change and option for enhancing food provision, and (3) feedbacks in which environmental and socio-economic consequences of adaptation are evaluated. One of the first such projects examines the rice-wheat rotational cropping system that is central to the Indo-Gangetic Plain food system and where yields have been stagnating or declining in recent years. Millions of people depend on this cropping system for staple food grains. Production in this region is highly sensitive to climate variability and may be negatively affected by competitive demands for water. Several plant diseases can have catastrophic impacts on rice-wheat production in this environment and active participation by plant pathologists is, therefore critical to solve new emerging problems.

Conclusion

The climate change effects are challenging to study but of potentially great importance. The impact of climate change on disease for a given plant species will depend on the nature of the effects climate change has on both the host and its pathogens. Climate change could first affect disease directly by either decreasing or increasing the encounter rate between pathogens and host by changing ranges of the two species. Disease severity should be positively correlated with increases in virulence and aggressiveness of pathogens. However, both of these effects on disease will be mediated by host resistance and encounter rates, which in turn are potentially affected by climate change. Thus a positive effect of climate change on conduciveness to infection or pathogen aggressiveness or virulence could be offset by a concurrent increase in resistance, yielding no net change in disease impact. Species at highest risk for an increase in disease will be those with positive effects of climate change on encounter rates, environmental conduciveness to infection, aggressiveness, or virulence, but with neutral or negative effects on resistance. The effects of climate change on all these traits will ultimately be modified by the evolutionary potential of host and pathogen. Certainly, all agree on paucity of knowledge prompting a need to generate new empirical data on host–pathogen biology under a changing climate. Therefore, there is a need to encourage the investigations to study the effect of changing climate on host-pathogen biology to manage the plant diseases in their best effective ways. There is also a need to promote the research based on effect of climate change on biocontrol agents and their interaction with plant pathogens to make these biological control strategies more effective against the plant disease under changing climate.

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Erosion of environmental ecosystems is affecting biodiversity and microbial ecology. Together with declining nature-relatedness this is reducing human contact with immunomodulatory organisms found in natural environments â€“ reflected in differences in skin microbes. This is increasingly being recognised as a risk factor for chronic inflammatory diseases. Full size image. In: Modern Trends in Microbial Biodiversity of Natural Ecosystem (Eds. A. Sinha, B. K. Sharma and M. Srivastava), pp. 79-91. Biotech Books, New Delhi.Â Singh, V. and Kumar, P. 2012. Morphological, Pathogenic and Molecular Diversity in Rhizoctonia solani KÃ¼hn Causing Sheath Blight of Rice. In: Modern Trends in Microbial Biodiversity of Natural Ecosystem (Eds. A. Sinha, B. K. Sharma and M. Srivastava), pp. 79-91. Biotech Books, New Delhi. Download. Singh, V. and Kumar, P. 2012. Morphological, Pathogenic and Molecular Diversity in Rhizoctonia solani KÃ¼hn Causing Sheath Blight of Rice. In: Modern Trends in Microbial Biodiversity of Natural Ecosystem (Eds. A. Sinha, B. K. Sharma and M. Srivastava), pp. 79-91. Biotech Books, New Delhi.