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Impact of Climate change on plant diseases: an overview

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ABSTRACT

Global food production must increase by 50% to meet the projected demand of the world's population by 2050. Meeting this difficult challenge will be made even harder if climate change melts portions of the Himalayan glaciers to affect 25% of world agriculture production in Asia by influencing water availability. Thus, climate changes are in response to changes in the hydrosphere, biosphere and other atmospheric and interacting factors. Human activities driven by demographic, economic, technological and social changes have a major impact on climate change. We describe research on the effects of changes in temperature, CO_2 and ozone concentrations, precipitation, and drought on the biology of pathogens and their ability to infect plants and survive in natural and agricultural environments. Climate affects all life stages of the pathogen and host and clearly poses a challenge to many pathosystems. Pest and disease management has played its role in doubling food production in the last 40 years, but pathogens still claim 10–16% of the global harvest. Influences of climate change on production and quality of plants, outlines key links between plant diseases, climate change and food security, and highlights key disease management issues to be addressed in improving food security in a changing climate.

Keywords:

I.INTRODUCTION

The earth's climate has always changed in response to changes in the cryosphere, hydrosphere, biosphere and other atmospheric and interacting factors. It is widely accepted that human activities are now increasingly influencing changes in global climate that influence ecology (Pachauri and Reisinger, 2007; Ahanger *et al*., 2013). Climate change is a major environmental challenge worldwide. Green house gases (GHG) *viz*., water vapour (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs) and Ozone (O3) in the atmosphere trap reflected radiation to warm the earth surface (Mahato, 2014). According to Inter-govenrmental Panel on Climate Change (IPCC, 2007); the planet earth is experiencing a climate change and atmospheric CO2 is a major GHG, which increased by nearly 30% and temperature by 0.3- 0.6°C (Chakraborty *et al*., 2000). This global climate changes by various factors (Pachauri and Reisinger, 2007 and Pachauri *et al*., 2014) and influence all the three major elements of disease triangle, *viz*., host, pathogen and environment (Legreve and Duveiller, 2010). Atmospheric CO_2 concentration, temperature, changes in precipitation patterns and frequency of extreme weather phenomena affect crop growth and production due to high disease presence altered under these conditions (Rosenzweig and Tubiello, 2007; Ghini *et al*., 2008 and Chakraborty, 2011).

The battle against plant disease is not a new one, and plant disease management is essential for our continued ability to feed a growing human population. The Great Irish Hunger is one striking example of the impact of plant disease in 1845 more than a quarter million Irish people starved as the result of an epidemic of potato late blight (M.M. Kennelly *et al*. 2005)**.** It is now recognized that climate change will affect plant diseases together with other components of global change, i.e. anthropogenic processes such as air, water and soil pollution, long-distance introduction of exotic species and urbanization (Regniere, 2012). Anthropogenic activities have been found to spread of many diseases like sudden oak death (Prospero *et al*., 2009). Elevated temperature and CO_2 concentration have impact on plant-disease interaction (Lopez *et al*., 2012) and posing a higher threat perception of late blight (*Phytophthora infestans*) of potato, blast (*Magnaporthe grisea*) and sheath blight (*Rhizoctonia solani*) of rice (Kobayashi *et al*., 2006). Disease management strategies should be re-oriented in changing climate for sustainable food production. Although, plant diseases play an important role in agriculture, a limited amount of information on the potential impacts of climate change on plant diseases is available (Harvell *et al*., 2002 and Garrett *et al*., 2006).

II.EFFECTS OF CLIMATE CHANGE ON PLANT DISEASES

Effect of temperature on plant diseases

Temperature affects the chain of events in disease cycles such as survival, dispersal, penetration, development and also reproduction rate for many pathogens. Due to changes in temperature and precipitation regimes, climate change may alter the growth stage, development rate, pathogenicity of infectious agents, and the physiology and resistance of the host plant (Charkraborty and Datta, 2003). Generally high moisture and temperature favors and initiate disease development, as well as germination and proliferation of fungal spores of diverse pathogens. Spores of *Erisiphe chichoracearum*and, *Erysiphe necator* germinate at temperature from 7 to 32°C with a RH of 60 to 80% and 6 to 23°C with a RH of 33 to 90 % (Khan and Khan, 1992; Bendek *et al*., 2007). Moderate temperature is the best for fungal growth that cause plant disease. Late blight of potato and tomato infects and reproduces most successfully at high moisture when temperatures are between 7.2°C and 26.8°C. Infection of *Eucalyptus* sp. by *Phytophthora cinnamomi* due to increased soil temperature of 12-30°C (Podger *et al*., 1990). Temperature also plays a vital role for the occurrence of bacterial diseases such as *Ralstonia solanacearum*, *Acidovora xavenae* and *Burkholderia glumea* and bacteria also proliferate in the areas where temperature dependent diseases have not been previously observed (Kudela, 2009). Incidence of virus and other vector borne diseases also alter due to temperature. Mild and warmer winters make aphids easy to survive thus spreading *Barley yellow dwarf virus* (BYDV) and also increase viruses of potato and sugar beet (Thomas, 1989; Mackerron *et al*., 1993).

Effect of Rising CO_2 Levels

Chakraborty *et al*. (2008) remind us that the current CO_2 concentration in the atmosphere, (which is set to exceed 400 ppm in a few years) is higher than the range of concentrations (180–300 ppm) measured from ice cores going back 650,000 years. The main causes of this global [CO_2] increase are fossil fuel burning and land-use changes (mainly deforestation) (Cerri *et al*. 2007; Paterson and Lima 2010). The increase in [CO_2] and the concentration of other greenhouse gases has already resulted in an increase in the global average temperature of 0.6–0.7°C over the last century (Mann *et al*. 1998; Walther *et al*. 2002; Benvenuti, 2009). The effects of elevated CO_2 concentration on plant diseases can be positive or negative, but majority of the cases disease severity increased (Manning and Tiedmann, 1995).Since 1750, global emissions of radioactively active gases, includingCO_2, have increased rapidly, a trend that is likely to accelerate if increase in global emissions cannot be curbed effectively. Man-made increases in CO_2 emissions have come from industry, particularly as a result of the use of carbon-based fuels. New races may evolve rapidly under elevated CO_2, as evolutionary force act on massive pathogen populations by a combination of increased fecundity and infection cycles under favorable microclimate within enlarged canopy (Chakraborty, 2013). High CO_2 concentrations may result in denser canopies with higher humidity that favor pathogens and lower plant decomposition rates observed in high CO_2 situations could increase the crop residue on which disease organisms can overwinter, resulting in higher inoculum levels at the beginning of the growing season, and earlier and faster disease epidemics. 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 (Coakley *et al.,* 1999). An increase in CO_2 levels may encourage the production of plant biomass and alternatively, a high concentration of carbohydrates in the host tissue promotes the development of biotrophic fungi such as rust (Chakraborty *et al*., 2002). Thus, an increase in biomass can modify the microclimate and affect the risk of infection (Lambers *et al*., 2008). Increased size of plant organs, leaf area, leaf thickness, more numbers of leaves, higher total leaf area/plant, stems and branches with greater diameter are resulted from increased CO_2 levels (Bowes, 1993 and Pritchard *et al*., 1999). Dense canopy favours the incidence of rust, powdery mildew, *Alternaria* blight, *Stemphylium* blight and anthracnose diseases.

Under elevated CO_2 conditions, potential of dual mechanism i.e., reduced stomata opening and altered leaf chemistry results in reduced disease incidence and severity in many plant pathosystems where the pathogen targets the stomata (Mcelrone *et al*., 2005). In soybean, elevated concentration of CO_2 and O3 altered the expression of 3 soybean diseases, downy mildew *(Perenospora manshurica)*, brown spots *(Septoria glycines)* and sudden death syndrome *(Fusarium virguliforme)* and response to the diseases varied considerably (Eastburn *et al*., 2010)

Effect of moisture on plant disease

Moisture, in the form of free water or high humidity, is necessary for infection, reproduction, and spread in many plant pathogens, although some pathogens cause disease in dryer conditions. Because environmental conditions favourable to disease development vary greatly among plant pathogens, it is vital to understand the environmental requirements of individual plant pathogens before predictions on responses to climate change can be made. With increased temperature various models on climate change predict frequent and extreme rainfall events and higher atmospheric water vapour concentrations. These encourage the crops to produce healthier and larger canopies that retain moisture as leaf wetness and RH for longer periods and results in condition conducive for pathogens and diseases such as late blights and vegetable root diseases including powdery mildews (Coakley *et al*., 1999). High moisture favours foliar diseases and some soil borne pathogens such *Phytophthora, Pythium, R. solani*and *Sclerotium rolfsii*. Drought stress affect the incidence and severity of viruses such as *Maize dwarf mosaic virus (*MDMV*)* and *Beet yellows virus* (BYV) (Olsen *et al*., 1990 and Clover *et al*., 1999).

Another important aspect of water is its quality, e.g. whether it is affected by pollution or salination. Use ofexcessive amounts of irrigation can cause salination problems for crop growth directly or through sea wateringress. This has direct effects on crop production, but also many indirect effects through effects on pest, pathogenand interactions with beneficial microbes, since many abiotic stress mechanisms are also biotic stress response mechanisms, particularly abscisic acid, jasmonate, ethylene and calcium regulation (Fujita *et al*., 2006). Pathogen spores from water- or salt-stressed plants, for example, can have increased infectivity (Wyness & Ayres, 1985).Furthermore, cold and drought stress and stress-relief can affect disease resistance expression (Newton & Young, 1996; Goodman&Newton, 2005). Thus, effects on suchinteractions should be considered in terms of not only thecrop as a substrate for the pest, pathogen or other microbe, but also the efficacy of defense mechanisms. Many nutrients affect disease development and will be influenced indirectly by climate change (Walters&Bingham, 2007), particularly for nitrogen, is another plant growth-related trait that has high genetic variability (Chardon *et al*., 2010), a large environmental interaction (e.g. Hirel*et al*., 2001), is a modern breeding target and has direct effects on pathogen fecundity (Baligar*et al*., 2001).

Direct effects of climate change on plant pathosystem

Plant pathologists have long considered environmental influences in their study of plant diseases: the classic disease triangle emphasizes the interactions between plant hosts, pathogens and environment in causing disease (Garrett 2008; Klopfenstein *et al*. 2009; Grulke 2011). Climate change is just one of the many ways in which the environment can move in the long term from disease-suppressive to disease-conducive or vice versa (Baker *et al*. 2000; Fuhrer 2003; Perkins *et al*. 2011). Therefore, plant diseases could be even used as indicators of climate change (Logan *et al*. 2003; Garrett *et al*. 2009), although there may be other bio-indicators which are easier to monitor. Long-term data sets on plant disease development under changing environmental conditions are rare (Scherm 2004), but, when available, can demonstrate the key importance of environmental change for plant health (Jeger and Pautasso 2008; Fabre *et al*. 2011). Plant health is predicted to generally suffer under climate change through a variety of mechanisms, from accelerated pathogen evolution and shorter incubation periods to enhanced abiotic stress due to mismatches between ecosystems and their climate and the more frequent occurrence of extreme weather events (Chakraborty and Datta 2003; Chakraborty 2005; Chakraborty *et al*. 2011; Ghini *et al*. 2011; Newton *et al*. 2011; Sutherst *et al*. 2011). Drought is expected to lead to increased frequency of tree pathogens, mainly through indirect effects on host physiology (Desprez-Loustau *et al*. 2006). Drier conditions may also have direct effects on pathogens, as shown by the invasive exotic species. Reduction in frost due to increased average minimum temperatures implies the removal of a limiting factor for pathogens such as *Fusarium circinatum* (the causal agent of pine pitch canker), with consequent enlargement of the area at risk, particularly in Europe (Watt *et al*. 2011). Conversely, for pathogens that take advantage of frost-wounds in order to infect the host (e.g. Seiridium cardinale on cypress species), a decreased occurrence of frost could lead to reduction in disease incidence (Garbelotto, 2008). In the case of insect-vectored diseases: if warmer temperatures translate into additional insect generations (as they often do), obviously this will increase transmission rates of the invasive pathogen (Dobson 2009; Robinet *et al*. 2011). Already observed climate warming appears to have been associated with shifts in plant hosts for some fungi (Gange *et al*. 2011). Some regional consequences of climate change on plant health are already present: for example, although changes in cropping practices may also be playing a role, there have been progressively earlier and more frequent observations of *Phytophthora infestans*in Finland (Hannukkala *et al*. 2007). In forests of Canada and the Western USA, warmer temperatures have been associated with large-scale outbreaks of bark beetles (Bentz *et al*. 2010; Woods *et al*. 2010; Woods 2011). Plant pests are already causing substantial crop losses in most regions of the world (Rosenzweig *et al*. 2001; Barnes *et al*. 2010; Haq*et al*. 2011). An increase in extreme weather events and a trend towards warmer temperatures may well worsen these impacts (Roos *et al*. 2010; Thomas 2010; Hakala *et al*. 2011; Madgwick *et al*. 2011; West *et al*. 2012).

Impact of Climate Change on Disease Management Practices

Results indicate that climate change could alter stages and rates of development of the pathogen, modify host resistance, and result in changes in the physiology of host-pathogen interactions. However, many plant disease forecast models have not lived up to the expectations that they would play a major role in better disease management. Amongst the reasons, the presumption of a disease forecast model is that it makes future projections of major events in disease development – and most present forecast models do not (Seem, 2001). An exciting development in this area is the possibility to use weather forecasts as input into disease models and consequently output “true disease forecasts”. As weather forecasts improve together with more accurate estimations of environmental variables useful for plant disease models, as such precipitation and leaf wetness duration, it will be possible to provide seasonal estimates of disease likelihood and forecast outbreaks. This is especially interesting for crop management for the reason that unnecessary sprays has a significant impact on production costs, and no timely applications may result in inadequate control (Way and van Emden, 2000). The revolution in web-based technologies has led to great strides in the development and employment of decision support systems for growers and pest management specialists. Disease predictive systems are intended to be management aids. With a few exceptions, these systems typically do not have direct sustained use by growers. Rather, their impact is mostly pedagogic and indirect, improving recommendations from farm advisers and shaping management concepts (Shaw, 2008). The degree to which a system is consulted depends on the amount of perceived new, actionable information that is consistent with the objectives of the user. Often this involves avoiding risks associated with costly disease outbreaks (McCown, 2007).

Plant health and climate change: Conclusions and research gaps

Climate change effects on plant health are likely to be unique, both in terms of direct and indirect impacts. Maintaining plant health across the planet, in turn, is a key requirement for climate change mitigation, as well as the conservation of biodiversity and the provision of ecosystem services under global change. Since there are inherent limits in our understanding of plant pathosystems and their interactions with future climates, it is likelythat a diversity of management strategies, including learning from our mistakes, is a better choice than a single, inflexible solution. To maintain ecosystem health and services under variable, unpredictable or unknown conditions, we need more resilient systems, decentralization, participatory research and breeding networks. At the same time, increased involvement of the many stakeholders and scientists from outside plant pathology shows the importance of considering trade-offs with other objectives. Increasing diversity would be in favour of a land-sharing approach, but may be relevant also to land-sparing scenarios (e.g. at the margin of fields), depending on the spatial and temporal scale and the type of diversity (genetic, species turnover, ecosystem) considered.

Table1. Effects of fungal infections on ozone sensitivity of plants

Pathogen	Host	Effect	References
Pyrenochaeta lycopersici	Tomato	Increased brown root rot disease due to elevated concentration of ozone.	(Manning, 1974)
Verticicladiella procera	White pine	Increased root disease with ozone stress.	(Skelly *et al*., 1983)
Puccinia recondita f. sp. *tritici*	Wheat	Increased number of pustules and urediospores at or past shooting stage only by the effect of ozone.	(Tiedemann *et al*, 1992)
Tranzschelia prunspinosa	Peach	Enhanced spread of disease	(Badiani *et al*., 1992)
Botrytis cinerea	Cucumber & Tomato	Strong increase in number of diseased tomato and cucumber fruits under UV	(Honda *et al*., 1977)

		radiation	
Sclerotinia sclerotiorum	Egg plant, Cucumber	Strong increase of apothecia formation under UV radiation	(Honda and Yunoki, 1977)
Puccinia recondita f. sp. *tritici*	Wheat	Rust infections increased on rust sensitive wheat cultivar	(Biggs *et al.*, 1984)

III.CONCLUSION

1. Climate change is a complex issue, but climate is changing there is no doubt about it.
2. Greenhouse gases emission are the main culprit for global warming
3. Change in the level of Ozone, CO_2 and other gases that are present in atmosphere will influence plant diseases by modifying host physiology and resistance.
4. Change in temperature and precipitation will influence disease epidemiology.

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