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# Scenario of plant diseases under changing climate

**Shikha Sharma, KS Hooda and Pooja Goswami**

## Abstract
This review paper starts with highlighting the studies on effect of elevated CO2 and Temperature on Crop-disease Interactions under enhanced greenhouse gas emissions, and implications on achievement of food security and development goal. The complexities of climate change, and the biotic responses to this, makes prediction of the future impact of climate change on emerging infectious diseases (EIDs) of plants difficult, but broad trends can be surmized. Global circulation models predict that high latitudes and elevations will warm to a greater degree than the global mean warming, and that winter and nocturnal minimum temperatures will continue to increase. A changing climate is likely to bring changing patterns of climate variability, including extreme meteorological events, such as precipitation anomalies and greater temperature variations. The precise impacts of climate change on insects and pathogens is somewhat uncertain because some climate changes may favor pathogens and insects while others may inhibit a few insects and pathogens. The analysis of the potential impacts of climate change on plant diseases is essential for the adoption of adaptation measures, as well as for the development of resistant cultivars, new control methods or adapted techniques, in order to avoid more serious losses.

**Keywords:** Climate change, CO2 concentration, emerging infectious diseases

## Introduction
Greenhouse gas concentrations in the atmosphere are being altered by human activities, thus causing global climate change. These activities, intensified after the Industrial Revolution at the end of the eighteenth 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) [38]. Since 2000, the growth rate in $CO_2$ concentration is increasing more rapidly than in the previous decades (Canadell *et al*., 2007) [6]. Similar trends have been observed for methane ($CH_4$), nitrous oxide ($N_2O$), and other greenhouse gases (Spahni *et al*., 2005; IPCC, 2007) [39, 33]. 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) [33].
Geographical distribution of plant pathogenic prokaryotes, like other pathogens occurring in plants, is predominantly influenced by several factors such as: local climate, distribution of host plants, dispersal ability of pathogens, presence of animal vectors, and adaptability of pathogens to local conditions, the ability pathogens to infect new host plants, and resistance of local cultivars. Starting from 1961, the implication of climate for plant pathogens and diseases they cause has been deeply analysed repeatedly in the Annual Review of Phytopathology series (Hepting 1963 and Garrett *et al*. 2006) [17, 31, 12].
Climate change may be due to natural internal processes (within climates system) or to external processes which may be brought about by natural forcing (such a volcanic eruptions and solar variation) or anthropogenic forcing. There is consensus among climatologists that global warming is occurring and refers to the gradual increase in global average surface temperature, as one of the consequence of radiative forcing caused by anthropogenic emissions. However, confidence in attributing some observed climate change phenomena to anthropogenic or natural processes is limited by uncertainties in radiative forcing, as well as by uncertainty in processes and observations (Bater *et al.* 2008) [3].
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. 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.

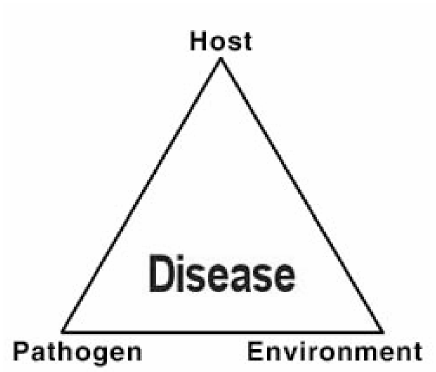
Climate change is just one of the many ways in which the environment can move in the long term from disease-suppressive to disease-conducive or vice versa. (IPCC, 2013) [34].

**Climate change in agriculture sector**

Agriculture sector is particularly sensitive to climate change. From an agricultural perspective, macroclimate can be defined as the climate above or outside a plant canopy, in contrast to microclimate, the climate within the plant canopy. While many events in plant disease cycles occur within the plant canopy, the macroenvironment often exerts a major influence on disease occurrence and pathogen dissemination.

**Role of environment in causing plant diseases**

**Plant Disease Triangle**




The three legs of the triangle – host, pathogen, and environment – must be present and interact appropriately for plant disease to result. If any of the 3 factors is altered, changes in the progression of a disease epidemic can occur. The major predicted results of climate change –increases in temperature, moisture and CO2 – can impact all three legs of the plant disease triangle in various ways.

**Components of climate change**

Mahlman (1997) [25] commented on and updated the summary of IPCC's 1995 report. He classified the relative certainty of change into several categories. "Virtually certain facts" include that atmospheric concentrations of greenhouse gases would continue to rise, largely caused by human activities such as burning of fossil fuel and changes in land use. These gases, which may remain in the atmosphere from a decade to centuries, act to heat the planet because of absorption and re-radiation of infrared radiation. Changes in other radioactively active substances (e.g. sulphur aerosols) and increased cloudiness caused by greater evaporation in a warmer climate may offset some of the greenhouse effect. Another "virtually certain fact" is that earth's surface has warmed about 0.5 ± 0.2°C during the past century. The expected rate of increase is now at 0.1±C per decade (Kerr, 1998) [21].

Under "virtually certain projections" (99% likely to happen) Mahlman (1997) [25] included the forecast that the stratosphere would continue to cool as $CO_2$ levels rise and that global mean concentrations of water vapor in the lower troposphere would increase (approximately 6% per °C warming).

**How rising temperatures will affect pathogens and disease**

Temperature has potential impacts on plant disease through both the host crop plant and the pathogen. Research has shown that host plants such as wheat and oats become more susceptible to rust diseases with increased temperature; but some forage species become more resistant to fungi with increased temperature (Coakley *et. al.* 1999) [10]. Many mathematical models that have been useful for forecasting plant disease epidemics are based on increases in pathogen growth and infection within specified temperature ranges. Generally, fungi that cause plant disease grow best in moderate temperature ranges. Temperate climate zones that include seasons with cold average temperatures are likely to experience longer periods of temperatures suitable for pathogen growth and reproduction if climates warm. For example, predictive models for potato and tomato late blight (*Phytophthora infestans*) show that the fungus infects and reproduces most successfully during periods of high moisture that occur when temperatures are between 7.2°C - 26.8°C (Wallin *et al.* 1950). Earlier onset of warm temperatures could result in an earlier threat from late blight with the potential for more severe epidemics and increases in the number of fungicide applications needed for control.

**How rising $CO_2$ levels will affect pathogens and disease**

Increased $CO_2$ levels can impact both the host and the pathogen in multiple ways. Some of the observed $CO_2$ effects on disease may counteract others. Researchers have shown that higher growth rates of leaves and stems observed for plants grown under high $CO_2$ concentrations may result in denser canopies with higher humidity that favor pathogens. 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) [10].

A "very probable projection" would have a greater than 90% chance of being correct; under this category,). Mahlman (1997) [25] predicted that a doubling of atmospheric $CO_2$ (from a current concentration of 360 ppm) would result in a warming between 1.5 and 4.5±°C. The rate of evaporation would increase in a warmer climate, which would lead to an increase in global precipitation of 2 ± 0.5% per 1±°C warming. Higher latitudes in the Northern Hemisphere are expected to experience above-average increases in both temperature and precipitation. Mahlman's final category ("probable projections," which have a greater than two thirds chance of occurring) included the forecast that there would be decreases in soil moisture because of increased temperatures, although this could be offset by simultaneously increased precipitation. Further, changes in mean climate would probably be accompanied by changes in the frequency and magnitude of climate extremes; globally, this would include an increased probability of warm events and decreased probability of cold events.

Hansen *et al.* (1998) [15, 16] proposed an easily understood climate index based on heating degree days and frequency of precipitation to monitor climate change. For Asia and western North America, the index indicates that climate change should be evident already. Indeed, an increasing number of recent studies involving analyses ranging from satellite temperature data. Hansen *et al.* (1998) [15, 16] to borehole temperature is lending support to the notion that climate change is occurring now. Mahlman (1997) [25] concluded that "it is virtually certain that human-caused greenhouse warming is going to continue to unfold, slowly but inexorably, for a long time into the future." What is much less certain is the magnitude of climate change and its impacts on biological and ecological processes and on human enterprises.Nowadays, the environment can influence host plant growth and susceptibility; pathogen reproduction, dispersal, survival and activity; as well as host-pathogen interaction. 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. A plant disease is a dynamic process in which a host and a pathogen intimately related to the environment are mutually influenced, resulting in morphological and physiological changes (Gaumann, 1950) [13].

**Impact of increased concentration of atmospheric co$_2$ on plant growth**.

$CO_2$ enrichment promotes changes in plant metabolism, growth and physiological processes. There is a significant increase in the photosynthetic rate and a decrease in the transpiration rate per unit leaf area. While total plant transpiration sometimes increases, due to the larger leaf area (Jwa and Walling, 2001; Li *et al*., 2003) [20, 24]. The stimulus on photosynthesis is due to the reduction in competition between the atmospheric $CO_2$ and $O_2$ being fixed by the ribulose 1, 5- bisphosphate carboxylase-oxygenase (RUBISCO) enzyme. The atmospheric concentration of $O_2$ normally inhibits $CO_2$ absorption by plants, and triggers photorespiration. With a rise in $CO_2$ concentration, the inhinhibition of photosynthesis by $O_2$ tends to decrease due to an increase in the $CO_2$:$O_2$ ratio.

**Impact of the increase in co$_2$ concentration on plant diseases**

In a review about the effects of the increase in $CO_2$ concentration on plant diseases covering the period of 1930 to 1993, Manning & Tiedemann (1995) [26] observed an upward trend in diseases. The analyzed the potential effects of higher $CO_2$ concentration on plant diseases, based on the plant responses to this new environment. The increase in plant biomass production, i.e., the increase in production of shoots, leaves, flowers and fruit, represents more tissue that can be infected by pathogens. Increased carbohydrate contents can stimulate the development of sugar-dependent pathogens, such as rusts and powdery mildews. Increases in canopy density and plant size can promote higher growth, sporulation and spread of leaf infecting fungi, which require high air humidity, but not rain, as rusts, powdery mildews and leaf necrotrophs. The increase in crop residues can represent better survival conditions for necrotrophic pathogens. The reduction in stomatal opening can inhibit stomata- invading pathogens, such as rusts, downy mildews and some necrotrophs. The shortened growth period and accelerated ripening and senescence can reduce the infection period for biotrophic pathogens, and increase the necrotrophic pathogen populations. The increase in root biomass increases the amount of tissue that could be infected by mycorrhiza or soilborne pathogens, but can compensate the losses inflicted by the pathogens. Higher root exudation can stimulate both pathogens and antagonistic microbiota in the rhizosphere (plant growth promoters). In a more recent review on the subject, Chakraborty and Pangga (2004) [9]concluded that of the 26 diseases studied to date most of them increased in severity when in $CO_2$- enriched environments. The effects of increased $CO_2$ atmospheric concentration are often observed in the host plant, resulting in alterations in the host-pathogen relationship. According to Braga *et al*. (2006) [5], the exposure to $CO_2$- enriched atmospheres can change inducible defensive responses in plants against pathogens. These changes occurred in individual metabolites and were dependent on cultivar resistance patterns.

Hibberd *et al*. (1996a, b) [18, 19] concluded that the benefits of $CO_2$ fertilization on growth depend on the nature of plant resistance. Delayed growth of the pathogen germ tube and appressorium reduced the germination percentage of conidia on leaves and extended the incubation period in a controlled environment with high $CO_2$ concentration. Consequently, there was a reduction in disease severity. Furthermore, pathogen penetration takes place through the stomata, and the increase in $CO_2$ reduces leaf stomatal density. On the other hand, the latent period was not altered and spore production was significantly higher.

Drought stress and disease stress may have additive effects on plants, as observed for infection by *Maize dwarf mosaic virus* (Mayek-Perez *et al*. (2002) [27] and *Macrophomina phaseolina* (Olson *et al*., 1990) [28], may cause more deleterious effects on their hosts under drought conditions, though it is unclear whether this is because of increased infection rates under drought or because of increased impacts per infection event.

Mayek-Perez *et al*. (2002) [27] suggest that the concentration of carbohydrates in host tissues as a result of drought stress may benefit pathogens such as *M. phaseolina* that can survive in extremely dry soils.

**How changes in moisture will affect pathogens and disease**

Moisture can impact both host plants and pathogen organisms in various ways. Some pathogens such as apple scab, late blight, and several vegetable root pathogens are more likely to infect plants with increased moisture – forecast models for these diseases are based on leaf wetness, relative humidity and precipitation measurements. Other pathogens like the powdery mildew species tend to thrive in conditions with lower (but not low) moisture. More frequent and extreme precipitation events that are predicted by some climate change models could result in more and longer periods with favorable pathogen environments. Host crops with canopy size limited by lack of moisture might no longer be so limited and may produce canopies that hold moisture in the form of leaf wetness or high canopy relative humidity for longer periods, thus increasing the risk from pathogen infection (Coakley *et. al.* 1999) [10]. Some climate change models predict higher atmospheric water vapor concentrations with increased temperature – this also would favor pathogen and disease development.

**Major taxonomic groups of pathogens causing plant emerging infectious diseases**

Viruses, fungi and bacteria are the major pathogens causing plant EIDs. Viruses cause just under half (47%) of the reported plant EIDs that we reviewed, which is a similar percentage to that for human (44%) and wildlife (43%) EIDs. However, bacteria cause a lower proportion (16%) of plant EIDs compared with human (30%) or wildlife (30%) EIDs and fungi represent a higher proportion (30%) of plant EID pathogens when compared with those of humans (9%) or wildlife (! 10%).

**Factors cited as the drivers of emergence of plant EIDS**

As with wildlife EIDs, pathogen introduction is the most important driver of plant EIDs. Weather conditions are also important, which might be related to the sensitivity of plants to humidity and moisture levels and the responses of plant pathogens to weather events. Although we are not aware of recombination being cited as a cause of disease emergence in humans or wildlife (with the notable exception of influenza viruses and HIV-1), this process was identified as the cause of emergence for 2% of the plant diseases that we reviewed.

**Factors cited as the cause of disease emergence by pathogen group**

Analysis of the factors cited as the cause of disease emergence for the three most significant taxonomic groups of pathogens [bacteria), fungi and viruses shows that, although introduction is the most, or second most, important driver for each pathogen group, the percentage of EIDs driven by introduction declines proportionately with size of pathogen, being lowest for fungi and highest for viruses. Weather conditions are major drivers of bacterial and fungal plant EIDs, but are relatively unimportant for plant EIDs that are caused by viruses, where changes in vector populations are the most important driver after pathogen introduction. Interestingly, although agricultural changes were identified as important drivers of plant EIDs caused by fungi and viruses, they were not mentioned as drivers of bacterial diseases.

**Climate change as a driver of emerging infectious diseases of plants**

The complexities of climate change, and the biotic responses to this, makes prediction of the future impact of climate change on emerging infectious diseases (EIDs) of plants difficult, but broad trends can be surmized. Global circulation models predict that high latitudes and elevations will warm to a greater degree than the global mean warming, and that winter and nocturnal minimum temperatures will continue to increase. A changing climate is likely to bring changing patterns of climate variability, including extreme meteorological events, such as precipitation anomalies and greater temperature variations [Rosenzweig *et. al.,* 2001]. Climate change can lead to disease emergence through gradual changes in climate (e.g. through altering the distribution of invertebrate vectors or increasing water or temperature stresses on plants) and a greater frequency of unusual weather events (e.g. dry weather tends to favour insect vectors and viruses, whereas wet weather favours fungal and bacterial pathogens) [Agrios, 2005] [1]. Thus, climate change can lead to the emergence of pre-existing pathogens as major disease agents or can provide the climatic conditions required for introduced pathogens to emerge. Harvell *et al.,* 2002 [32] suggested that milder winters, higher nocturnal temperatures and higher overall temperatures will enable increased winter survival of plant pathogens, accelerated vector and pathogen life cycles, and increased sporulation and infectiousness of foliar fungi. Because climate change will enable plants and pathogens to survive outside their historic ranges, Harvell *et al.,* 2002 [32] predicted an increase in the number of invasive pathogens. The ranges of several important crop insects, weeds and plant diseases have already expanded northward [Rosenzweig *et. al.,* 2002]. Range expansion of the grey leaf blight of corn, caused by the fungus *Cercospora zeae-maydis*, was first noticed during the 1970s, and, in the past two decades, has become the major cause of corn yield loss in the USA [Rosenzweig *et. al.,* 2002]. Extreme weather events include spells of unusually high temperature, high rainfall and long periods of drought. Increased drought might result in loss of corn yield. Aflatoxin, a compound that lowers corn quality and which is a health risk to humans, is related to drought conditions and its concentration is raised during crop-water deficits, which favour the growth of the fungus Aspergillus flavus (the producer of aflatoxin) in the weakened crop.

**Plant diseases in relation to climate change**

It was emphasise by Coakley *et al*. (1999) [10] that most of what has been said about plant disease in relation to climate change is based on qualitative, rule-based reasoning. For example, it seems plausible but not sure that (*i*) increased air temperature would result in a poleward expansion of the geographical range of pathogens and in more generations per year; (*ii*) elevated winter temperatures would increase survival and hence the amount of initial inoculum in many pathosystems; (*iii*) and that greater continental dryness during summer would reduce risk of infection by pathogens that require leaf wetness or saturated soils for infection. In case of vector-borne diseases, climate influences the spatial distribution, intensity of transmission, and seasonality of diseases transmitted by vectors. Climate change can have positive, negative or neutral impact on individual plant-bacterial pathogen interactions. Climate is doubtless of primary importance in the distribution of plant pathogens and their host plants. The main climatic factors that pathologists are concerned with are precipitation, temperature, humidity, fog and dew, wind, and radiation. Besides, there are other factors, such as plant succession, amount of disturbance of the environment, light and length of season, the effect of which on the distribution of many plant pathogens are difficult to evaluate. upto 2009, about 400 bacterial plant pathogens are known (Kůdela *et al*. 2002) [23]. Bacteria multiply with astonishing rapidity, and their significance as pathogens stems primarily from the fact that they can produce tremendous numbers of cells in a short period of time (Agrios 2005) [1].

For example, generation time (doubling time) for *Pseudomonas syringae* pv. *phaseolicola* lies between 2.1–5.2 h (Klement *et al*. 1990). Growth studies in liquid medium showed the mean doubling time of four strains of *Acidovorax avenae* subsp. *Avenae* decreased from 77 min to 57 min when the temperature increased from 29°C to 36°C (Schaad & Summer 1980) [36].

Bacterial diseases of plants occur in every place that is reasonably moist or warm, and they affect all kinds of plants. Bacterial diseases are particularly common and severe in the humid tropics, but under favorable environmental conditions they may be extremely destructive anywhere (Agrios 2005) [1]. When we take into account a huge multiplicity of bacteria and their very sensitiveness and adaptiveness to environment, it is evident that study of bacterial communities can also provide climate-change clues.

The most likely effects of climate change are shifts in the geographical distribution of hosts, pathogens (including their potential vectors) and altered crop losses. Changes may occur in the type, amount, and relative importance of pathogens and affect the spectrum of diseases affecting a particular crop (Coakley *et al*. 1999) [10]. However, these authors also emphasise that the effects of climate change on plant pathogens, plant diseases and plant disease management maybe less important than changes in land-use patterns, transgenic technologies, trade activities and availability of chemical pesticides.

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 adaptation measures, as well as for the development of resistant cultivars, new control methods or adapted techniques, in order to avoid more serious losses (Chakraborty and Pangga, 2004; Ghini, 2005) [9, 14]. Anon. (2008) [2] reported that *Rhizoctonia solani* produced symptoms in the form of scattered lesions after 3 days of inoculation at temperature range 26.0- 33.3$^0$C and relative humidity 84- 86 per cent as compared to temperature range 8.8-20$^0$C and relative humidity 86-92 per cent after 20 days of inoculation. Despite the threat posed by climate change to plant protection in the near future, there are few reports about this subject (Garrett *et al.*, 2006) [12]. This review aims to report and discuss the impacts of climate change on the spatial and temporal distribution of plant diseases, the effects of increased concentration of atmospheric $CO_2$ and the consequences for disease control.

Once environment and diseases are closely related, climate change will probably alter the geographical and temporal distribution of phytosanitary problems. The host plant agro climatic zone likewise, pathogens and other microorganisms related to the disease process will be affected. Therefore, new diseases may arise in certain regions, and other diseases may cease to be economically important, especially if the host plant migrates into new areas (Coakley *et al*., 1999) [10].

According to Chakraborty *et al.* (2000a) [7], 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 because of narrow host range. Regarding necrotrophs, the range of hosts can be extended due to crop migration.

## Emerging of heat-loving bacteria

Most 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) [37].

## Climate change and plant health care system

The predicted changes in future climate may affect growth of crop plants and their interaction with plant pathogens. It seems therefore possible to meet any predicted harmful effects. However, in spite of the fact that plant diseases are crucial constrain on plant productivity, the effects of changing weather systems on plant health are difficult to show conclusively. Climate change is likely to be a gradual process that will give researchers, plant breeders, plant health care practitioners, managers and farmers some opportunity to adapt. Both predicted (and unpredicted) disease consequence of climate change on plant health can most likely be minimised by such manners as follows: (*i*) to build a solid knowledge base on the impact a consequence of climate change for various parts of the world (Anonymous 2009); (*ii*) to determine the potential for adaptation under potential changes in pathogen pressure due to climate change (or other factors) (Garrett *et al.* 2006) [12]; (*iii*) to maintain a high index of suspicion for changes in the plant pathosystem; (*iv*) to monitor systematically occurrence of diseases and animal pests in each field and region and keep records of severity, frequency over time; (*v*) to develop new varieties adapted to changed climate through traditional or transgenic methods; (*vi*) the farm advisory system could be used not only to disseminate knowledge but also to adopt and introduce the new integrated control of organisms injurious to plants.

## Conclusion

1. The precise impacts of climate change on insects and pathogens is somewhat uncertain because some climate changes may favor pathogens and insects while others may inhibit a few insects and pathogens.
2. The preponderance of evidence indicates that there will be an overall increase in the number of outbreaks of a wider variety of insects and pathogens.
3. The possible increased use of fungicides and insecticides resulting from an increase in pest outbreaks will likely have negative environmental and economic impacts for agriculture.
4. The best economic strategy for farmers to follow is to use integrated pest management practices to closely monitor insect and disease occurrence. Keeping pest and crop management records over time will allow farmers to evaluate the economics and environmental impact of pest control and determine the feasibility of using certain pest management strategies or growing particular crops.
5. Global climate change affect humans, livestock and wildlife as plant diseases impact negatively on human wellbeing through agricultural and economic loss, and also have consequences for biodiversity conservation.
6. The analysis of the potential impacts of climate change on plant diseases is essential for the adoption of adaptation measures, as well as for the development of resistant cultivars, new control methods or adapted techniques, in order to avoid more serious losses.

## Future Thrust

The impacts on abiotic diseases associated with the occurrence of extreme values of environmental variables will not be discussed, in spite of an expected increase in their incidence so it could be study.

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