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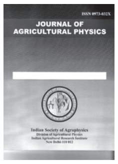

Review Article

Emerging Crop Pest Scenario under the Impact of Climate Change – A Brief Review

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ABSTRACT

Human activities are altering greenhouse gas concentration in the atmosphere and causing global climate change. Climate change also influences the ecology and biology of insect pests and diseases. Increased temperature causes migration of insect species towards higher latitudes, while in the tropics higher temperatures might adversely affect specific pest species. Likely impacts of any change in climate on population of pests are manifold. They range from expansion in the geographical range, increased risk of invasion in new area, change in overwintering patterns, change in crop pest synchrony; change in pest complexes on spatial and temporal bases and finally pests management strategy. The impacts of climate change can be positive, negative or neutral, since these changes can decrease, increase or have no impact on insect pests and diseases, depending on specific location of each region or period. These impacts will also be observed on plants and other organisms as well as on other agro ecosystem components. However, these impacts cannot be easily determined, and consequently, specialists from several areas must go beyond their disciplinary boundaries by placing the climate change impacts in a broader context. This review focuses on the discussion of different aspects related to the effects of climate change on insect pests and plant diseases. Recent studies using data of predicted future climate is associated with pests and diseases to predict their distribution under climate change scenarios.

Key words: Crop pests, Climate change, Elevated CO_2, Pest management

Introduction

The intensified human activities started with the Industrial Revolution at the end of the eighteenth century resulted in the use of natural resources such as fossil fuel. Increasing the use of wood for timber and fuel caused large scale deforestation. Forest land was converted into human habitat and agricultural lands. Concentration of greenhouse gases, namely carbon dioxide, methane, Chlorofluorocarbons and nitrous oxide in the atmosphere started increasing. Increased concentration of these gases started absorbing long wave radiation emitted by the earth surface and the atmosphere got progressively warmer, which is called global warming. As a result of global warming, global average temperature is increasing, rainfall distribution and intensity are getting altered, cyclonic activities on the sea surface are forming more frequently, frequency of floods and droughts are increasing. Alteration in all these climatic parameters over a period of time is collectively known as climate change.

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In the atmosphere concentration of carbon dioxide (CO_2) has reached levels significantly higher than that in the last 650 thousand years (Siegenthaler *et al*., 2005). Since 2000, the range of CO_2 change concentration has been increasing more rapidly than in the previous decades (Canadell *et al.,* 2007). Similar trends have been observed for methane (CH_4), nitrous oxide (N_2O), and other greenhouse gases (Spahni *et al.,* 2005; IPCC, 2007). There is now clear evidence for an observed increase in global average temperatures and change in rainfall during the 20th century (Easterling, 1999; IPCC, 2001) around the world. Because of the increasing concentrations of those greenhouse gases and temperature, there is much concern about future changes in climate and its direct or indirect effect on agriculture (Aggarwal, 2003) including crop and animal production, protection from biotic and abiotic stresses.

The association and importance of the weather on the development of plant pest and 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. During the eighteenth century and the beginning of the nineteenth century, the effects of factors such as nutrition, air humidity and wind on plant disease occurrence started to be studied (Colhoun, 1973). Now a days, the environment can influence host plant growth and susceptibility; pest reproduction, dispersal, survival and other activities; as well as host-pest/pathogen interaction.

Global Warming and Climate Change

Climate is defined as the prevalent pattern of weather observed over a prolonged period of time. Climate variables (e.g., temperature, precipitation, wind speed) can be time-averaged on a daily, monthly, yearly or decade basis.

The Intergovernmental Panel on Climate Change (IPCC 2001**)** pointed out that most of the global warming observed over the last 50 years was attributable to human activities. During the past 100 years global-average surface temperatures have increased by approximately 0.6^{o}C (the largest increase of any century during the past 1,000 years) (Houghton *et.al*., 2001). The phenomenon of temperature increase, especially in the seasons of winter and spring, has also been observed in South Asia and worldwide. The trend of averaged precipitation was not different within past 40 years, but the dry and wet seasons have become more and more distinct (Lee 2008). Analysis of precipitation data over the past 100 years showed that the total precipitation did not change, but the frequency of light rain decreased and the frequency of heavy rainfall increased. Heavy rain often destroyed/damaged life and properties on the ground surface. Insects are likely to be affected by climate change because they are ectothermic and sensitive to temperature (Bale *et al.,* 2002). The effect can be direct, through the influence of climatic factors on the insects' physiology and behavior (Parmesan 2007), or indirect, as mediated by host plants, competitors or natural enemies (Lastvka 2009; Thomson *et al.,* 2010**).**

The global mean annual temperatures at the end of twentieth century were almost 0.6^{o}C above those recorded at the end of the nineteenth century. The 1990s were, on average, was the warmest decade since the instrumental measurement of temperature started. The CO_2 concentration was 280 ppm between 1000 and 1759AD. The Intergovernmental panel on climate change (IPCC) scenario indicates that it will be between 605 and 655ppm by 2070. Methane has increased since pre-industrial times from 700 to 1750 ppb, accounting for about 15% of global warming. Methane concentration in the atmosphere is presently increasing at around 1% per year.

Effect of Enhanced Atmospheric Carbon Dioxide on Plant Growth

Plants grow through the well-known process of *photosynthesis,* utilizing the energy of sunlight to convert water from the soil and carbon dioxide from the air into sugar, starches, and cellulose-the *carbohydrates* that are the foundations of the entire food chain. CO_2 enters a plant through its leaves. Greater atmospheric concentrations tend to increase the difference in partial pressure between the air outside and inside the plant leaves, and as a result more CO_2 is absorbed and converted to carbohydrates. Crop species vary in their response to CO_2. Wheat, rice, and soybeans belong to a physiological class (called *C3 plants*) that responds readily to increased CO_2 levels. Corn, sorghum, sugarcane, and millet are *C4 plants* that follow a different pathway. The latter, though more efficient photo synthetically than C3 crops at present levels of CO_2, tend to be less responsive to enriched concentrations.

Higher levels of atmospheric CO_2 also induce plants to close the small leaf openings known as *stomata* through which CO_2 is absorbed and water vapor is released. Thus, under CO_2 enrichment crops may use less water even while they produce more carbohydrates. This dual effect will likely improve water-use efficiency, which is the ratio between crop biomass and the amount of water consumed. At the same time, associated climatic effects, such as higher temperatures, changes in rainfall and soil moisture, and increased frequencies of extreme meteorological events, could either enhance or negate potentially beneficial effects of enhanced atmospheric CO_2 on crop physiology.

Effect of Elevated Carbon Dioxide on Crop Pest Dynamics

A larger crop canopy and denser foliage resulted from enhanced CO_2 level in the atmosphere will create more relative humidity, thereby making micro-environment more favorable to pests. Increases in food quality, i.e. increase in the nitrogen content of plants due to high temperature, can results in sudden resurgence of population of pests. Moreover under condition of stress, plant defensive systems are less effective and they become more susceptible to pest attack (Coviella and Trumble 1999). Some more findings on effects of enhanced CO_2 on crop pests is given in the table 1.

Extinction might occur in some species because of insufficient genetic diversity, but the species might survive in areas that become favorable as a result of change. If climate change is slow, selection might enable the species to adapt. Otherwise, the species may become extinct locally as conditions become more favorable for their competitors.

Effects of Higher Temperature in Agriculture

In middle and higher latitudes, global warming will extend the length of the potential growing season, allowing earlier planting of crops in the spring, earlier maturation and harvesting, and the possibility of completing two or more cropping cycles during the same season. Crop-producing areas may expand pole ward in countries such as Canada and Russia. Many crops have become adapted to the growing-season day

Table 1. Effect of increasing atmospheric carbon dioxide on plant insect interaction

Increasing atmospheric carbon dioxide leads to	Reference
Increasing...	
Food consumption by caterpillars	Osbrink *et al.,* 1987
Reproduction of aphids	Bezemer *et al.,* 1999
Predation by lady beetle	Chen *et al.*, 2005
Carbon based plant defenses	Coviella and Trumble, 1999
Effect of foliar application and *B.thuringiensis*	Coviella and Trumble, 2000
Decreasing...	
Insect development rates	Osbrink *et al.*, 1987
Response to alarm pheromones by aphids	Awmarck *et al.,* 2000
Parasitism	Roth and Lndroth, 1995
Effect of transgenic *B. thuringiensis*	Coviella *et al.,* 2000
Nitrogen-based plant defense	Coviella and Trumble, 1999

lengths of the middle and lower latitudes and may not respond well to the much longer days of the high latitude summers. In warmer, lower latitude regions, increased temperatures may accelerate the rate at which plants release CO_2 in the process of *respiration,* resulting in less than optimal conditions for net growth. When temperatures exceed the optimal for biological processes, crops often respond negatively with a steep drop in net growth and yield. If night time temperature rises and day time temperature falls as is expected from greenhouse warming projections—heat stress during the day may be less severe than otherwise, but increased night time respiration may also reduce potential yields. Another important effect of high temperature is accelerated physiological development, resulting in hastened maturation and reduced yield.

Impact of Enhanced Temperature on Crop Pest Dynamics

Insects are cold-blooded organisms - the temperature of their bodies is approximately the same as that of the environment. Therefore, temperature is probably the single most important environmental factor influencing insect behavior, distribution, development, survival, and reproduction. Some researchers believe that the effect of temperature on insects largely overwhelms the effects of other environmental factors (Bale *et al.,* 2002). It has been estimated that with a 2°C temperature increase, insects might experience one to five additional life cycles per season (Yamamura and Kiritani 1998). 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). For every insect species there is a range of temperature within which it remains active from egg to adult stage. Lower values of this range are called 'threshold of development' or 'developmental zero'. Within the favorable range, there is an optimum temperature at which most of the individuals of a species complete their development. Exposure to temperatures on either side of the range exerts an adverse impact on the insect by slowing down the speed of development.

Climate factors that influence the growth, spread, and survival of crop diseases include temperature, precipitation, humidity, dew, radiation, wind speed, circulation patterns, and the occurrence of extreme events. Most analyses conclude that in a changing climate, pests may become even more active than they currently are, thus posing the threat of greater economic losses to farmers (Coakley *et al.,* 1999). Higher temperature, humidity and greater precipitation, on the other hand, are likely to result in the spread of plant diseases, as wet vegetation promotes the germination of spores and the proliferation of bacteria and fungi, besides influencing the life cycle of soil nematodes and other organisms.

The possible impacts of increased atmospheric temperature on crop pests found by other researchers are summarized in table 2. The effect of increased temperature on crop pest dynamics which needs attention on priority basis is discussed below.

1. Increase in number of generation

Some crop pests are "stop and go" developers in relation to temperature. They develop more rapidly during periods of time with suitable temperatures. Increased temperatures will accelerate the development of these types of insects – possibly resulting in more cycles of generations (and crop damage) per year. (Awmack *.et al.,* 1997). Climate change may influence the physiology, abundance, phenology and distribution of the insect pests (Lastvka 2009), and the major factors include temperature, CO_2 concentration, precipitation, natural enemies and their host plant. With temperatures within their viable range, insects respond to higher temperature with increased rates of development, more number of generation with less time between generations. Very high temperatures reduce insect longevity. Warmer winters will reduce winterkill, and consequently there may be increased insect populations in subsequent growing seasons.

Collier *et al.* (1991) simulated the future attack of Cabbage rootfly (*Delia radicum*) in UK increasing daily mean temperature by 3°C, 5°C, 10°C. An increase of 3°C in mean daily

Table 2. Effect of enhanced atmospheric temperature on crop pest dynamics

Increasing atmospheric temperature leads to	Reference
Increasing...	
Northward migration	Parmesan, 2006
Migration up elevation gradients	Epstein *et al.,* 1998
Insect developmental rates and oviposition	Regniere, 1983
Potential for insect outbreaks	Bale *et al.,* 2002
Invasive species introductions	Dukes and Mooney, 1999
Insect extinctions	Thomas *et al.,* 2004
Decreasing...	
Effectiveness of insect biocontrol by fungi	Stacy and Fellowes, 2002
Reliability of economic threshold levels	Trumble, John and Butler, Casey, 2009
Insect diversity in ecosystems	Erasmus *et al.,* 2002
Parasitism	Hance *et al.,* 2007; Fleming and Volney, 1995

temperature would cause the cabbage root fly to become active about a month earlier in the year than at present. Under such conditions, the emergence of flies from the overwintering population would be less synchronized, as the completion of diapause and post-diapause development would occur at the same time in different individuals within the population. However, these would continue to be three generation in a year. But with temperature increases of 5^{o}C , the fly would complete four generations each year.

2. Probable expansion of geographical range

One of the major effects of climate change will be an acceleration of species range shifts. Many insect species have geographic ranges that are not directly limited by vegetation, but instead are restricted by temperature. As the globe warms, those species directly limited by temperature will be able to expand northward in the northern hemisphere and southward in the southern hemisphere as rapidly as their dispersal mechanisms will allow. The species limited by vegetation will be able to expand their ranges only as rapidly as the vegetation range changes or in some cases by changing their host range.

Any increase in temperature is bound to influence the distribution of insects. It is predicted that a 1^{o}C rise in temperature would enable speed 200 km northwards (in northern hemisphere) or 40 m upward (in altitude). The areas that are not favorable at present due to low temperature may become favorable with rise in temperature. Minimum temperature rather than maximum temperature plays an important role in determining the global distribution of insect species, hence any increase in temperature will result in a greater ability to overwinter at higher altitudes, ultimately causing a shift of pest intensity from south to north. On the other hand area with an optimum temperature for insect habitat today may become less favorable with a rise in atmospheric temperature.

As the species richness of insect tends to increase with temperature, it is presumed that with an increase in temperature more species will be gained than lost. Overwintering survival and timing of the commencement spring are important at higher latitudes, leading to population build-up of, for example, *Heliothis zea*, thereby endangering maize and soybean crops. It has been noted that insect population under increasing temperature is under move towards higher latitudes and elevation.

3. Natural enemy-pest interactions

Among insects there is a distinction between the specialist and generalists, and there response to changing climate condition may be different. Generalist species have good dispersal capability and are best suited for tracking the changing climate, migrating with climatic shifts and taking the opportunity to feed on new part of the range. Specialist species, even of the highly dispersive type, may not benefit as the plant species they feed on may not be present in the new region. All species will come under strong selection pressures, which may be different from those exerted when the climate is stable. This may also be applicable to natural enemies, which play a decisive role in limiting the pest population in the newer areas. Bioclimatic studies on insect hosts and there natural enemies have confirmed potential physiological limitation for their geographical spread. For example, both *Telemonus ullyetti* and *Trichogrammatidea lutea* are egg parasites of cotton bollworm (*Helicoverpa armigera*). But *T.leutea* is most effective at 28°C, 25% RH and LD(light:dark i.e., day:night duration) 14:10 where as *T.ullyetti* dominates at 22°C, 70% RH and LD 10:14 (Kfir *et al.,* 1988).

4. Pest management inputs

Pesticides use often leads to scourges of pest resurgence and secondary pest outbreaks as well as adverse affect on ecosystem and human health. The effect of weather on pests management operations are also significant. After application of chemicals, these are not to be washed away. Similarly wind resulting in drifting problems is likely to cause damage.

For the insect pests that produce one generation annually or their development lasts several years, or the number of generations is limited by the photoperiod, most facts remain unchanged by climate change. For those species which could breed two or more generations in a year, they may gradually adapt to the new climatic conditions by shifting the temperature thresholds, effective temperature totals and critical photoperiod lengths without showing any appreciable changes in their development. Most literature tends to emphasize climate-induced increases in insect population which indicates a higher allocations for pest management inputs in future. It is also logical that climate change will also reduce insect abundance in some aspects. New strategy would be required to manage all these pest.

Pest Management under Climate Change Scenario

Weather based pest forewarning systems are decision support tools that help growers to assess the risk of outbreaks of economically damaging crop pests at present and future climate change scenario. Using information about weather, crop, and/or insects, warning systems advise growers or other crop managers when they need to take an action - usually to apply a insecticidal spray to prevent pest outbreaks and avoid economic losses. Pest-warning systems are key elements of Integrated Pest Management (IPM) efforts to reduce excessive use of chemical pesticides. There are several potential incentives for growers to adopt pest warning systems. By substituting risk assessment based spray timing for traditional calendar based pesticide spraying, growers can reduce spray frequency, limiting the health and environmental hazards of pesticide use while presenting an environmentally friendly image to customers. The five components of an IPM program are prevention, monitoring, correct disease and pest diagnosis, development and use of acceptable thresholds, and optimum selection of management tools. The management strategies available include genetic control, cultural control, biological control, and chemical control. What management strategy is most relevant depends in part on the particular pest. Pest management strategy coupled with weather based pest forewarning system forms the 'Expert System' or 'Decision Support System' for pest management. Need for these systems will be felt increasingly in the future.

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