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Review Article

Predictions of Climate Change Impacts on Agricultural Insect Pests vis-à-vis Food Crop Productivity: a Critical Review

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Abstract

Climate change is a broad range of global phenomena created predominantly by burning fossil fuels, which add heat-trapping gases called greenhouse gases to Earth's atmosphere. Insects are poikilothermic animals and thus sensitive to climate warming. Global warming and climate change trigger major changes in diversity and abundance of arthropods, geographical distribution of insect pests, population dynamics, insect biotypes, herbivore plant interactions, activity and abundance of natural enemies, species extinction, and efficacy of crop protection technologies. Climate change also will have severe impacts on insects, especially honeybees, which pollinate crop plants and thus affect crop production highly. Combined effects of these will increase the extent of crop losses, and thus, will have a major bearing on crop production and food security. Prediction of changes in geographical distribution and population dynamics of insect pests will be useful for adapting pest management strategies to mitigate the adverse effects of climate change on crop production. This paper summarized the different ways in which climate change impacts on insect pests and will increase the extent of crop losses. Governments should respond to climate change both by reducing the rate and magnitude of change by reducing greenhouse gas emissions (mitigation), and by adapting to its impacts. Many impacts can be avoided, reduced or delayed by mitigation, but adaptation will be necessary to address impacts resulting from the warming which is already unavoidable due to past emissions. Therefore, there is a need to take a concerted look at the likely effects of climate change on crop protection and devise appropriate measures to mitigate the effects of climate change on food security.

1. Introduction

The world's climate has changed frequently during human history. Yet the term 'climate change' usually refers to those changes that have been observed since the early 1900s and includes anthropogenic and natural drivers of climate (Masters and Norgrove, 2010). Climate change is defined as "a change in the state of the climate that can be identified (for example, by using statistical tests) by changes in the mean and/or variability of its properties, and that persists for an extended periods, typically decades or longer"**.** This definition is not limited to changes contributed directly or indirectly by human activity. It therefore, includes changes to the climate caused by natural phenomena such as volcanic eruptions. While humans are unable to influence the effects of such natural phenomena on the climate, such events will interact with the influences of human activities. Human influences will be superimposed on natural variability (IPCC, 2007).

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Over the past hundred years, the global temperature has increased by 0.8^0c (IPCC, 2007). If greenhouse gases concentration continue to rise, future warming is likely to be even more dramatic, with global surface temperatures likely to increase 1.1 - 6.2°c by the end of this century (Diffenbaugh1 et al., 2008). This change is attributed mainly to the overexploitation and misuse of natural resources for various anthropogenic developmental activities such as increased urbanization, deforestation, rising fossil fuel burning and industrialization. These have emitted, and are continuing to emit increasing quantities of greenhouse gases into the Earth's atmosphere. These greenhouse gases include carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), and a rise in these gases has caused a rise in the amount of heat from the sun withheld in the Earth's atmosphere, heat that would normally be radiated back into space. This increase in heat has led to the greenhouse effect, resulting in climate change (Adams et al., 1998).

The main characteristics of climate change are increases in average global temperature (global warming); changes in cloud cover and precipitation particularly over land; melting of ice caps and glaciers and reduced snow cover; and increases in ocean temperatures and ocean acidity due to seawater absorbing heat and carbon dioxide from the atmosphere (Adams et al., 1998). Besides, climate change results in frequent droughts and floods, increased intensity and frequency of heat and cold waves, outbreaks of insect-pests and diseases, etc. affecting profoundly, many biological systems and ultimately human beings (Fand et al., 2012). Higher temperatures will make dry seasons drier, and conversely, may increase the amount and intensity of rainfall; making wet seasons wetter than at present (Isman, 1997).

Climate change is concerned with everyone since it poses potential threat to environment, and agricultural productivity and production throughout the world. It has implications for livelihood and survival of human beings (Pareek et al., 2017). Crop and livestock yields are directly affected by changes in climatic factors such as temperature and precipitation and the frequency and severity of extreme events like droughts, floods, and wind storms. Climate change may also change the types, frequencies, and intensities of various crop and livestock pests (Adams et al., 1998).

Climate and weather patterns are of primary importance for the distribution, development, and population dynamics of insects. Insects are cold-blooded organisms and hence the temperature of their bodies is approximately the same as that of the environment. Therefore, temperature is the most important environmental factor influencing insect behavior, distribution, development, survival, and reproduction. Insect physiology is primarily driven by temperature and thus phenology, reproduction, and developmental rates significantly change when populations are exposed to different climatic regimes **(**Tobin et al., 2008; Lamichhane et al., 2014). One can safely presume that climate change would be a major causal factor in increasing pest damage to crops. Increasing outbreaks of key pests due to changing climate is virtually certain. With regard to food security, increasing pest damage is predicted to result in significant losses in food production and food supplies (IPCC, 2007).

Pest menace under the influence of climatic factors, at various stages of crop growth is one of the factors limiting agricultural productivity (Oerke et al., 1994)**.** Most analyses concur that in a changing climate, pests may become even more active than they are currently, thus posing the threat of greater economic losses to farmers (Coakley et al., 1999) and insect pests in agricultural systems are the major cause of damage to yield quantity (Rosenzweig et al., 2000). Insects represent the largest percentage (over 75 %) of the world's known animal species and there are more than one million species of insects that have been documented and studied by scientists. Crop plants used as a food by human beings are damaged by over 10,000 species of insects, and cause an estimated annual loss of 13.6% globally. Losses due to insect damage are likely to increase as a result of changes in crop diversity and increased incidence of insect pests due to global warming (Sharma, 2010).

In the future, pest species are likely to differ in their responses to global warming, changing the relative impacts of pests geographically and among crops. A warmer climate will alter at least two agriculturally relevant characteristics of insect pests. First, an individual insect's metabolic rate accelerates with temperature, and an insect's rate of food consumption must rise accordingly. Second, the number of insects will change, because population growth rates of insects also vary with temperature. The total energy consumption of a pest population (the "population metabolism") is proportional to the product of these two factors and directly relates to the crop yield loss caused by insect herbivory (Deutsch et al., 2018).

Climate change will affect significantly the diversity and abundance of insect-pests through geographic range expansion, increased overwintering survival and more number of generations per year, thereby increasing the extent of crop losses. It may result in upsetting ecological balance because of unpredictable changes in the population of insect-pests along with their existing and potential natural enemies (IPCC, 2007).

2. Ways in which Climate Change Aggravates Insect pests

The increase in temperature associated with climatic change, would impact crop pest insect populations in several complex ways like expansion of geographic ranges of insect pests, increased over-wintering survival, increase in number of generations and rapid population growth, risk of introducing invasive alien species, increased risk of invasion by migrant pests, impact on pest population dynamics and outbreaks, breakdown of host-plant resistance, changes in insect-host plant interactions, increased incidence of insect-vectored plant diseases, reduced effectiveness of biological control agents, disruption of plant-pollinator interactions, and reduced effectiveness of crop protection technologies (Diffenbaugh1 et al., 2008; Sharma, 2010; Fand et al., 2012; Pareek et al., 2017). Climate change impact on insects is one of the different ways by which it affects global agricultural food production and thus food security.

2.1. Expansion of geographic ranges

Not all places would be affected the same way by climate change. Effect of climate change is more in temperate insects, and it permits range expansion. Insects have optimal temperature where their population grows best. If the temperature is too cold or too hot, the population will grow more slowly. That is why the losses will be greatest in temperate regions, but less severe in the tropics. Temperate regions are not at that optimal temperature, so if the temperature increases there, populations will grow faster, but insects in the tropics are already close to their optimal temperature, so the populations will actually grow slower as the temperature becomes too hot for them (Deutsch et al., 2018).

Any increase in temperature is bound to influence the distribution of insects. It is predicted that a 1ºC rise in temperature would enable speed 200 km northwards (in northern hemisphere) or 40 m upward (in altitude). The areas which are not favorable for insects at present due to low temperature may become favorable with rise in temperature. Minimum temperature rather than maximum temperature plays an important role in influencing 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. Many insect species have geographic ranges that are not directly limited by vegetation, but instead are restricted by temperature (Pareek et al., 2017). Geographical distribution of insect pests confined to tropical and subtropical regions will extend to temperate regions along with a shift in the areas of production of their host plants, while distribution and relative abundance of some insect species vulnerable to high temperatures in the temperate regions may decrease as a result of global warming. These species may find suitable alternative habitats at greater latitudes (Sharma, 2010).

The general prediction is that if global temperatures increase, the species will shift their geographical ranges closer to the poles or to higher elevations and increase their population size (Bale et al., 2002). Warming in temperate region may lead to decrease in the relative abundance of temperature sensitive insect population. Mostly the Polar Regions are constrained from the insect outbreaks due to low temperature and frequently occurring frosts (Volney and Fleming, 2000). In the future, projected climate warming and increased drought incidence is expected to cause more frequent insect outbreaks in temperate regions also (Fand et al., 2012).

Distribution of insect pests will also be influenced by changes in the cropping patterns triggered by climate change. Major insect pests such as cereal stem borers

(*Chilo, Sesamia*, and *Scirpophaga*), the pod borers (*Helicoverpa, Maruca,* and *Spodoptera*), aphids, and white flies may move to temperate regions, leading to greater damage in cereals, grain legumes, vegetables, and fruit crops. Changes in geographical range and insect abundance will increase the extent of crop losses, and thus, will have a major bearing on crop production and food security (Sharma, 2010).

2.2. Pest population dynamics and outbreaks

Temperature is identified as a dominant abiotic (Fleming & Volney, 1995) regulating factor for insects, they respond to higher temperature with increased rates of development and with less time between generations. Warmer winters reduce winterkill and consequently induce increased insect populations in the subsequent growing season (Rosenzweig et al., 2000). Global increase in temperature within certain favorable range may accelerate the rates of development, reproduction and survival in tropical and subtropical insects. Consequently, insects will be capable of completing more number of generations per year and ultimately it will result in more crop damage (Fand et al., 2012). The assessment report from the Intergovernmental Panel on Climate Change (IPCC) predicts an increment in mean temperature from 1.1 to 5.4 °C toward the year 2100 (IPCC, 2007). It has been estimated that with a 2°C temperature increase insects might experience one to five additional life cycles per season (Ramya et al., 2012). Laboratory and modeling experiments support the notion that the biology of insect pests are likely to respond to increased temperatures (Fleming & Volney, 1995). With every degree rise in global temperature, the life cycle of insect will be shorter. The quicker the life cycle, the higher will be the population of pests (Pareek et al., 2017).

With temperatures within their viable range, insects respond to higher temperature with increased rates of development and 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. With warmer temperatures occurring earlier in the spring, pest populations can become established and thrive during earlier and more vulnerable crop growth stages (Rosenzweig et al., 2000).

In increasing temperature, tropical and subtropical insect species may advance continuously pole-ward (as far as their cold hardiness allows) because they lack diapause in their lifecycles. Temperate species will expand stepwise, as they need to reach the required temperature to allow them to develop one additional generation before reaching the diapause stage. In fact, diapause introduction is driven by photoperiodic cues (Tobin et al., 2008).

Since warmer temperature will bring longer growing seasons in temperate regions, this should provide opportunity for increased insect damage. A longer growth period may allow additional generations of insect pests and higher insect populations. The Mexican bean beetle and bean leaf beetle, both major pests of soybeans, presently have two generations in the U.S. Midwest and three in the Southeast. An additional generation may be possible in the Midwest if the growing season there lengthens (Rosenzweig et al., 2000).

Some pests which are already present, but only occur in small areas or at low densities, may be able to exploit the changing conditions by spreading more widely and reaching damaging population densities. Aphids, for instance, key pests of agriculture, horticulture, and forestry throughout the world, are expected to be particularly responsive to climate change because of their low developmental threshold temperature, short generation time, and considerable dispersal abilities (Sutherst et al., 2007). Projections of insect-crop dynamics through the 21st century suggest increases in pest pressure over much of the American Midwest, which could result in substantial increases in pesticide use to maintain productivity (Taylor et al., 2018).

Crop losses will be most acute in areas where global warming increases both population growth and metabolic rates of insects, primarily in temperate regions, where most grain is produced. As the climate warms and temperatures rise, we might lose more crops to insects. With warming climate insects' metabolism speeds up, and the faster they burn energy, the more they eat and reproduce. That means a greater number of increasingly hungry insects feeding on our staple crops. Using a mathematical model, scientists were able to predict just how much damage they could do: for every degree Celsius rise in temperature, insects could do an extra ten to twenty-five percent of damage to wheat, maize, and rice. Reduced yields in these three staple crops are a particular concern, because so many people around the world rely on them. Together they account for 42 % of direct calories consumed by humans worldwide. Increased crop losses will result in a rise in food insecurity, especially in those parts of the world where it is already rife, and could lead to conflict (Deutsch et al., 2018).

2.3. Increased incidence of insect-vectored plant diseases

It has been reported that, global climate warming may lead to latitudinal and altitude wise expansion of the geographic range of insect-pests (Parry and Carter, 1989), increased abundance of tropical insect species (Diffenbaugh et al., 2008), decrease in the relative proportion of temperature sensitive insect population, more incidence of insect-transmitted plant diseases through range expansion and rapid multiplication of insect vectors. Climate change creates new ecological niches, potentially allowing for the establishment and spread of plant pests and diseases to new geographical areas and from one region to another. Accordingly, it might also result in the emergence of new plant diseases and pests (Fahim et al., 2013). Climate change will also result in increased problems of insect-transmitted diseases through range expansion and rapid multiplication of insect vectors. These changes will have major implications for crop protection and food security, particularly in the developing countries, where the need to increase and sustain food production is most urgent (Pareek et al., 2017). Thus, with changing climate it is expected that the growers of crops have to face new and intense pest problems in the years to come (Fand et al., 2012).

Higher temperatures and greater precipitation in some regions are likely to result in the spread of plant pests and diseases. Higher temperatures reduce insect winterkill, and lead to increased rates of development and shorter times between generations. Wet vegetation promotes the germination of spores and the proliferation of bacteria, fungi, and nematodes. Prolonged droughts can encourage other pests and diseases; especially those carried by insects (Rosenzweig et al., 2000).

Increased temperatures, particularly in early season, have been reported to increase the incidence of viral diseases in potato due to early colonization of virus-bearing aphids, the major vectors for potato viruses in Northern Europe (Fand et al., 2012; Pareek et al., 2017).

2.4. Risk of introducing invasive alien species

Increasing temperatures and other alterations in weather patterns (e.g., drought, storm events) resulting from climate change are likely to have significant effects on outbreaks of pests and pathogens in natural and managed systems, and are also expected to facilitate the establishment and spread of invasive alien species (Backlund et al., 2008).

Even though the causes of biological invasions are manifold and multifaceted, changes in abiotic and/or biotic components of the environment (climate change, biological control) are recognized as primary drivers of species invasion (IPCC, 2007). Invasion of new insect-pests will be the major problem with changing climate favoring the introduction of insect-susceptible cultivars or crops (Gregory et al., 2009). Invasive insect, disease and weed pests are likely to benefit most from climate change, leading to increased pesticide and herbicide use or greater reductions in yield (Masters and Norgrove, 2010).

2.5. Disruption of plant-pollinator interactions

The economic significance of pollination is underscored by the fact that about three-quarters of the world's flowering plants depend on pollinators, and that almost a third of the food that we consume results from their activity. The majority of pollinators are insects, whose distributions, phenology, and resources are all being affected by climate change (Backlund, 2008). Pollination is one of the 15 major ecosystem services, a foundation for human life on earth (Kannan and James, 2009). Many of the economically important crops (Murugan, 2006) and majority of the flowering plants require insect pollinators like flies, butterflies, moths, beetles and especially bees for their reproduction and formation of fruits and seeds.

Pollination is currently under threat from mounting pressures exerted by growing population, depleting natural resource base and global climate change (Fand et al., 2012). Earlier studies have clearly shown that the population abundance, geographic range and pollination activities of important pollinator species like bees, moths and butterflies are declining considerably with changing climate (FAO, 2008). The climatic factors like temperature and water availability have been found to affect profoundly the critical events like flowering, pollination and fruiting in the life cycle of plants (Cleland et al., 2007). The majority of the flowering plants require insect pollinators like flies, butterflies, moths, beetles and especially bees for their reproduction and formation of fruits and seeds. Honey bees are perhaps the best known pollinators because of their floral fidelity. Insect pollination, mostly by bees, is necessary for 75% of all crops that are used directly for human food worldwide. Thus, entomophilous pollination is a fundamental process for the production of about one-third of the world human food (Klein et al., 2007). Some insects also contribute directly to the human economies through valuable products like silk by silk worms; lac by lac insects; and honey, wax and other products by honeybees (Murugan, 2006). Many pollinators have synchronized their life cycles with plant phenological events. Impending climate change is expected to disrupt the synchrony between plant-pollinator relationships by changing the phenological events in their life cycles and may thus affect the extent of pollination. The quality and the quantity of pollination have multiple implications for food security, species diversity, ecosystem stability and resilience to climate change (FAO, 2008).

2.6. Impact on crop-pest interactions

The increasing temperature and CO_2 have been found to exert both bottom-up and top-down effects on the tri-tropic interactions between crops, insects and natural enemies by means of certain physiological changes especially related to host-suitability and nutritional status. The CO_2 enriched environment reduces the nitrogen content of the plant tissue due to widening of Carbon: Nitrogen (C: N) ratio, thus cause a slight decrease in nitrogen-based defenses like alkaloids and in turn may increase in carbon-based defenses such as tannins. This enhances the feeding by insect herbivores in order to obtain sufficient nitrogen for their metabolism. Ultimately, it slows down the insect development and increases the length of life stages resulting in more foliage feeding than the normal (Fand et al., 2012).

3. Reduced Effectiveness of Crop Protection Technologies

Host-plant resistance, bio-pesticides, natural enemies, and synthetic chemicals are some of the potential options for integrated pest management. However, the relative efficacy of many of these pest control measures is likely to change as a result of global warming. Global warming will also reduce the effectiveness of host plant resistance, transgenic plants, natural enemies, biopesticides, and synthetic chemicals for pest management (Sharma, 2010).

3.1. Breakdown of host plant resistance

Host plant resistance is one of the ecofriendly options for managing harmful insect-pests of crops wherein the plant can lessen the damage caused by insect-pests through various mechanisms like antixenosis, antibiosis and tolerance. However, expression of the host plant resistance is greatly influenced by environmental factors like temperature, sunlight, soil moisture, air pollution, etc. Under stressful environment, plant becomes more susceptible to attack by insect-pests because of weakening of their own defensive system resulting in pest outbreaks and more crop damage. Thermal and drought stress associated breakdown of plant resistance have been widely reported. With global temperature rise and increased water stress, tropical countries like India may face the problem of severe yield loss in sorghum due to breakdown of resistance against midge *Stenodiplosis sorghicola* (Coq.) and spotted stem borer *Chilo partellus* Swinhoe (Fand et al., 2012).

3.2. Reduced effectiveness of biological control agents

Biological control of insect-pests is one of the important ecofriendly components of integrated pest management. Natural enemies of crop pests mainly, predators, parasitoids and pathogens are prompt density responsive in their action subjected to the action of abiotic components. Being tiny and delicate, natural enemies of the insect-pests are more sensitive to the climatic extremes like heat, cold, wind and rains. Precipitation changes due to climate change can also affect predators, parasites and pathogens of insect-pests resulting in a complex dynamics. With changing climate, incidence of entomopathogenic fungi might be favored by prolonged humidity conditions and obstinately be reduced by drier conditions. Thus, climate change can affect the natural enemies negatively, reducing their pest control efficacy. The effects of climate change are expected to act directly on all the trophic levels as well as indirectly on soil, water, the host crop, and hyper parasitoids (Fand et al., 2012).

4. Implications of Climate Change for Food Security

Climate change has serious impacts on diversity, distribution, incidence, reproduction, growth, development, voltinism and phenology of insect pests. Climate changes also affect the activity of plant defense and resistance, biopesticides, synthetic chemicals, invasive insect species, expression of *Bt* toxins in transgenic crops. Considering such declining production efficiency due to depleting natural resource base, serious consequences of climate change on diversity and abundance of insect-pests and the extent of crop losses, food security for 21st century is the major challenge for human kind in years to come Pareek et al., 2017).

The greatest challenge for humanity in the coming century is to double the present levels of food production to meet the needs of ever increasing population by sustainable use of shrinking natural resource base (Deka et al., 2008). The aggravating pest problems under changing climate regimes are expected to intensify the yield losses; threatening the food security of the countries with high dependency on agriculture (IPCC, 2007). The climate change is likely to affect the extent of entomophilous pollination by disrupting the synchrony between plant-pollinator life cycles (Kudo et al., 2004), with an estimated risk of reduction in world food production by one-third (Klein et al., 2007). This has major implication for food and nutritional security (FAO, 2008). This may have direct bearing on the livelihood of the rural poor as their survival is directly linked to outcomes from food production systems. The increased food prices resulting from declining food production may also impact negatively the urban population (Fand et al., 2012).

5. Conclusion

It has been noted that insect population under increasing temperature is under move towards higher altitudes and elevation. Various insect responds differently to atmospheric temperature and carbon dioxide rise and it is obvious of having varied impact depend on insect and regions. Due to the climate change there is an increase in number of insect pest population, out breaks of insects and increase in number of insect generations. This would definitely increase the damage caused by the insect, decrease the crop yields, increase the cost on crop protection and thereby affect the economy. Further, as with temperature, precipitation changes can impact insect pest, predators and parasitoids resulting in a complex dynamic situation. Climate change could upset the balance between insect crop pests and their natural enemies particularly in tropics leading to more frequent outbreaks (Kambrekar et al., 2015). Impacts of climate change on crop production mediated through changes in populations of serious insect-pests need to be given careful attention for planning and devising adaptation and mitigation strategies for future pest management programs. Therefore, there is a need to have a concerted look at the likely effects of climate change on crop protection, and devise appropriate measures to mitigate the effects of climate change on food security.

The current escalated use of fossil fuels which contributes to increased production of greenhouse gases and increase atmospheric CO_2 concentration that enhances increase of global warming should be shifted to renewable green energy. Deforestation should be controlled and afforestation should be encouraged so that forest plants can absorb and decrease CO_2 concentration and play significant role in regulating the environmental temperature at a fairly constant level.

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