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Climate Change Influencing Insect Invasions and Pest Outbreaks

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Abstract:

Climate and weather can substantially influence the development and distribution of insects. Anthropogenic induced climatic change arising from increasing levels of atmospheric greenhouse gases would, therefore, be likely to have a significant effect on agricultural insect pests. Current best estimates of changes in climate indicate an increase in global mean annual temperatures of 1°C by 2025 and 3°C by the end of the next century.

Such increases in temperature have a number of implications for temperature-dependent insect pests in mid-latitude regions. Changes in climate may result in changes in geographical distribution, increased overwintering, changes in population growth rates, increases in the number of generations, extension of the development season, changes in crop-pest synchrony, changes in interspecific interactions and increased risk of invasion by migrant pests.

2.1 Introduction:

Climate is important determinant of the abundance and distribution of biological species. Over past hundred years. The global temperature has increased by 0.8 °C and is expected to reach 1.1-5.4 °C by the end of next century. On the other hand, CO_2 concentration in the atmosphere has increased drastically from 280 to 370 ppm and is likely to be doubled in 2100 (IPCC, 2007).

Change in the global climate may affect the crop yields, incidence of pests and economic costs of agricultural production. Climate change is expected to have significant impacts on the distribution, phenology and abundance of many species over the next few decades.

The climate change impacts on insects may include shifts in species distributions with shift in geographic ranges to higher latitudes and elevations, changes in phenology with life cycles beginning earlier in spring and continuing later in autumn, increase in population growth rates and number of generations, change in migratory behaviour, alteration in crop-pest synchrony and natural enemy-pest interaction, and changes in interspecific interactions (Sutherst, 1991; Root *et al.,* 2003).

Extreme weather events such as intense rainstorms, wind or high temperatures also affect survival of insect populations. For species to survive changing climates, they must either adapt in situ to new conditions or shift their distributions in pursuit of more favorable ones. Changes in rainfall pattern also have implications for insect survival.

It is being predicted that frequency of rainfall would decrease, but its intensity would increase. This may lead to floods on one hand and long dry spells on the other. More intense rainfall as project under climate change may thus reduce incidence of small pests on crops. Aphid population on barley was negatively related to January mean minimum temperature and February total rainfall (Chander *et al*., 2003).

Pest management has potential to provide eco-friendly sustainable solution to obnoxious pest problems. However, the relative efficacy of pest management components such as, host-plant resistance, bio-pesticides, natural enemies and synthetic chemicals is liable to change as a result of global warming. It therefore becomes important to assess climate change impact on insect populations and adopt suitable pest management adaptations for their effective management.

2.2 Climate Change Impacts on Crop Pests:

Climate change will have both direct as well as indirect effects on insect populations. Temperature is the major factor in global climate change that directly affects insect development, reproduction and survival. Although insect responses to global climate change will vary, the effect of global warming in general has been predicted to increase intensity of herbivore pressure on plants. Climate change will also affect insects indirectly through their host plants.

2.2.1 Direct Effects of Climate Change on Insects:

A. Expansion of Habitat Range:

Any increase in temperature is bound to influence the distribution of insect populations. Species might expand into regions that become favorable as a result of climate change and withdraw from regions that cease to be favorable. Climatic warming will thus allow the majority of temperate insect species to extend their ranges to higher latitudes and altitudes. Insects being the cold-blooded, temperature is the most important environmental factor influencing their behaviour, distribution, development, survival, and reproduction. It is predicted that 1oC temperature increase would extend distribution of species 200 km northwards or 140 m upwards in altitude (Parry and Carter, 1989). There is a need to regularly observe activity of pests in different regions in terms of timing, population size and habitat ranges for drawing any meaningful conclusions.

B. Changes in Over-Wintering Success:

With rise in temperature, onset of hibernation may be delayed, while it may be suspended earlier than usual in spring thereby increasing period of activity of pests. The pests can therefore colonize crops more quickly during spring and earlier pest flights are known to occur after milder winters.

C. Change in Migrating Behaviour:

Minimum temperature plays important role in determining the global distribution of insect species rather than maximum temperature. Hence any increase in temperature will result in greater ability of insects to over-winter at higher latitudes. The global warming may affect thus migration and extend distribution of the pest further north.

D. Changes in Interspecific Interactions:

The effect of climate change on species distribution and abundance could involve not only direct effect on each species individually in an ecosystem but it may also influence interspecific interactions.

Rapeseed-mustard is infested by two aphid species, *Lipaphis erysimi* and *Myzus persicae*, the former being dominant during severe winters while the latter during mild winters (Chander and Phadke, 1994). With rise in temperature, higher incidence of *Myzus persicae* may be witnessed. Such faunal shifts may also take place in other crops. Likewise, pest-natural enemy interactions are also subject to influence of climate change.

E. Changes in Population Growth Rates:

Warming would affect temperate annual and multivoltine species in different ways and to different degrees. In case of multivoltine species such as aphids and some lepidopterans, higher temperatures would allow faster development rate probably allowing for additional generations within a year (Pollard and Yates, 1993).

It has been observed that tropical insects are relatively sensitive to temperature changes and are currently living very close to their optimum temperature (Deutsch et al., 2008). This implies that with 2-3^{o}C temperature rise, ambient temperature may exceed the upper limit of favorable temperature range, thereby adversely affecting growth and development of pests.

2.2.2 Indirect Effect Through Host Plants:

A. Effect of Increased Co2:

The elevated CO2 induces increased plant size and canopy density with high nutritional quality foliage and microclimate more conducive to pests. Under higher CO2, there is an increase in C: N ratio of plant foliage that increases feeding of herbivores in order to derive more amino acids. Rao et al. (2014) observed a higher relative proportion of carbon to nitrogen (C: N) in peanut foliage grown under elevated CO2 than ambient CO2 and reported that the pest incidence was likely to be higher in the future.

Elevated CO2 had a positive effect on BPH multiplication that resulted in more than doubling of its population compared to ambient CO2. Besides, honey dew excretion was also more under elevated CO2 (Prasannakumar *et al.,* 2012).

B. Effect of Increased Temperature:

Climate change may alter the interactions between the insect pests and their host plants (Sharma *et al*., 2010). Elevated temperature may cause breakdown of temperature sensitive resistance to certain insect pests.

2.3 Assessment of Impact of Climate Change on Pest Species:

Impact of global climate change on crop productivity and pest population can be assessed through experiments as well as through crop growth and insect population models.

2.3.1 Experimental Approach:

- **Direct Impact of Temperature:** Probable impact of temperature rise on insect populations can be known by comparing current and projected temperature conditions at a location with a species' favorable temperature range. Favorable temperature range for a species can be established by rearing it at a series of low to high constant temperatures in BOD incubators or growth chambers. Fecundity, hatching, development period, weight, survival and adult emergence should be recorded at as small intervals as possible to account for small differences in development period at different temperatures. Data on temperature dependent development period and survival can then be used to determine favorable temperature range and computing thermal constant and development thresholds for the species (Sujithra and Chander 2013, Selvaraj and Chander, 2015).
- **Indirect Impact of Co2:** Impact of CO2 on insect population via host plants can be studied through open top chambers (OTCs) and free air carbon dioxide enrichment (FACE). Prasanna kumar *et al.,* (2012) studied effect of elevated CO2 on BPH population in OTCs. It was observed that despite nutritive effect of elevated CO2 on rice crop, BPH induced losses were more under it owing to higher pest population as well as sucking rate.
- **Effect of Rainfall:** Distribution and frequency of rainfall may also affect the incidence of pests directly as well as through changes in humidity levels. It is being predicted that under climate change, frequency of rainfall would decline, while its intensity would

increase. Under such situation, incidence of small pests such as aphids, jassids, whiteflies, mites on crops may be reduced as these get washed away by heavy rains. Aphid population on wheat and other crops was adversely affected by rainfall and sprinkler irrigation (Chander, 1998).

2.3.2 Modelling Approaches:

- **Climate Matching:** Climate matching involves the computation of a “match index” to quantify the similarity in climate between two or more locations. The match index is based on variables such as monthly minimum and maximum temperatures, precipitation, and evaporation. Software packages for climate matching include BIOCLIM (Busby, 1991), and CLIMEX (Sutherst and Maywald, 1985). Climate matching may be used for climate change impact assessment by identifying those locations on the globe, where current climate is most similar to the predicted future climate at the location of interest.
- **Empirical Models:** Empirical models based on long-term data on pest incidence and weather variables can be used to assess the likely impact of climate change on pest status in a region. Chander *et al.* (2003) related aphid incidence on barley crop variety ‘DL-70’ during rabi season from 1985-86 to 1999-2000 to weather parameters and found an appreciable inter annual variation in aphid incidence probably due to climatic variability. The aphid population on barley exhibited a declining trend with time and it had a negative relationship with January mean minimum temperature and February total rainfall.
- **Simulation Models:** Simulation models have been used widely to assess climate change impact on yield of various crops in different agro ecological zones. However, biotic stresses like insects, pathogens, and weeds have largely been ignored in these studies. This requires that emphasis be laid on population dynamic simulation and their coupling with crop growth simulation models.

Insect population simulation model can be developed based on various bio-ecological factors of a species viz., fecundity, sex ratio, migration, abiotic and biotic mortality factors development thresholds and thermal constants (Reji and Chander, 2008; Sujithra and Chander, 2013; Selvaraj and Chander, 2015).

Population simulation model can be coupled to crop growth model at relevant plant processes depending on pest damage mechanisms. Crop-pest model can then be used to analyze impact of climate change on insect dynamics as well as crop-pest interactions.

- **Mitigation of Climate Change:**

Mitigation is the adoption of measures against sources of greenhouse gases to reduce their emission. For climate change mitigation, fossil fuel use in pest management related activities should be reduced. Pesticides manufacturing, transportation and power spraying requires a lot of energy and by curtailing pesticide consumption, greenhouse gas emission can be reduced. Pest management can play important role in mitigation of global climate change as it stresses on judicious use of agricultural inputs such as fertilizers and pesticides. Transplanted rice is one of the major sources of methane from agriculture along with dairy cattle.

Continuous flooding of rice fields leads to emission of methane, an important greenhouse gas and it also aggravates problem of plant hoppers on the crop. Likewise, excess use of nitrogenous fertilizers stimulates pests' population and is also responsible for nitrous oxide emission. Therefore, alternate wetting and drying as emphasized in pest management, mitigates methane emission and also reduces plant hopper incidence on the crop.

- **Adaptation to Climate Change:**

Pest management components such as host-plant resistance, bio-pesticides, natural enemies, and synthetic chemicals are exploited for management of pests. However, the relative efficacy of many of these pest control measures is likely to change as a result of global warming.

Climate change could affect efficacy of crop protection chemicals through (a) changes in temperature and rainfall pattern, and (b) morphological and physiological changes in crop plants (Coakley *et al.*, 1999). To sustain agricultural productivity under climate change, pest management adaptations assume significance to ensure effectiveness of management tactics against pests.

2.4 Pest Surveillance:

- **Monitoring:** Monitoring is the backbone of the IPM. The most important aspect of monitoring that needs to be fully exploited keeping in view the climate change scenario is detection of invasive species. The known ecological impacts of invasive species include loss of threatened and endangered species, altered structure and composition of terrestrial and aquatic communities, and reduction in overall species diversity.
- **Detection of Changes in Insect Distribution:** Climate change is expected to have significant impact on insect distribution and it thus becomes important to detect potential change in ranges of species distribution for their effective management. Generic modelling tools such as Bio Sim and CLIMEX have proved useful in such studies. Bio Sim uses available knowledge about the responses of particular species to key climatic factors to predict their potential geographic range and performance (Régnière and St-Amant, 2008).
- **Pest Forewarning:** Reliable medium-range weather forecast can help in proper timing of crop management practices such as sowing, irrigation, fertilizer application and pesticide application. This would increase efficiency of crop production and protection technology. Likewise, pest forecasting can help in cautioning farmers about impending pest situation and adoption of preventive measures to avert pest problems.

2.4.1 Pest Management Components:

Host-plant resistance, biological control, cultural control and chemical control are the major pillars of the IPM. These components are likely to be affected by climatic change and thus would need appropriate modifications for sustaining their effectiveness.

- **Host Plant Resistance:**

Breakdown of temperature-sensitive resistance under increased temperature regimes may lead to more rapid evolution of pest biotypes. Sorghum varieties that were resistant to sorghum midge, *Stenodiplosis sorghicola* (Coq.) in India became susceptible to the pest under high humidity and moderate temperatures in Africa (Sharma *et al.,* 1999).

With global warming and increased water stress, tropical countries like India might face the problem of higher yield losses in sorghum due to breakdown of resistance against the midge and spotted stem borer *Chilo partellus* Swinhoe.

- **Biological Control:**

Biodiversity is very important for abundance of insect pests and their natural enemies. It thus calls for increasing functional diversity in agro-ecosystems that are prone to climate change so as to improve their resilience and reduced pest induced yield losses.

Hosts might pass through vulnerable life stages faster at higher temperatures, reducing the time available for parasitism, thereby giving a setback to the survival and multiplication of parasitoids (Gutierrez, 2008).

There is thus a need to breed temperature tolerant natural enemies of pests. Increase in time of herbivore development due to changes in plant nutrition can make herbivore prey more susceptible to predation because of the ample opportunity available to predators.

Fungi such as *Metarhizium anisopliae*, *Beauveria bassiana*, Baculovirus, nuclear polyhedrosis virus (NPV), cytoplasmic virus and bacteria like Bt have great potential for development as microbial control agents. Because of their selectivity and minimal environmental impact, microbial control agents will be ideal components of integrated pest management programmes under climate change.

- **Cultural Control:**

Global climate change would cause alteration in sowing dates of crops, which may alter host-pest synchrony. There is need to explore changes in pest-host interaction under agronomic management adaptations.

Helicoverpa armigera and *Bemisia tabaci* are late season pests of cotton and by sowing till mid-May, crop can escape damage from these pests. Early sowing can be used to minimize pod borer, *H. armigera* damage to chickpea in North India, BPH damage in rice, and mustard aphid damage in Brassica crops.

- **Chemical Control:**

Climate change could affect efficacy of crop protection chemicals through (a) changes in temperature and rainfall pattern, and (b) morphological and physiological changes in crop plants (Coakley *et al.,* 1999).

An increase in probability of intense rainfall could result in increased pesticide wash-off and reduced pest control. In contrast, increased metabolic rate at higher temperature could result in faster uptake by plants and higher toxicity to pests.

Likewise, increased thickness of epicuticular wax layer under high CO_2 could result in slower or reduced uptake by host, while increased canopy size may hinder proper spray coverage and lead to a dilution of the active ingredient in the host tissue. The rates of pesticide application thus have to be modified according to new situations. Granular formulations may prove more effective as these are less liable to be washed by rainfall.

Reliable medium-range weather forecast can help in predicting rainfall and avoid pesticide application under imminent rainy conditions. Likewise, regular monitoring can help in undertaking control interventions at right time, thereby helping in managing small population levels easily and effectively.

Properly timed pesticide application, application coinciding with egg hatching, proves more effective than many ill-timed applications. Likewise, proper placement of pesticide is also equally important to ensure its efficacy against pests. In case of rice plant hoppers, pesticide application needs to be targeted at plant stems, because foliar spray on canopy proves of little or no use.

2.5 Conclusion:

Climate change is imminent and it has started showing its effect on organisms and insects are no exception to it. Climate change will also impinge upon efficacy of pest management components. It thus becomes very important to assess climate change impact on insects and pest management components and adopt appropriate mitigation and adaptation measures to sustain agricultural productivity.

Simulation models have been used for several applications in the area of pest management, which helped to increase the efficiency of field research greatly. These will be of even greater relevance in new emerging research areas such as climate change impacts on pests and crop yield, impacts of transgenic on environment, pest risk analysis for sanitary and phytosanitary requirements and pest forecasting.