International Journal of Chemical Studies

P-ISSN: 2349–8528
E-ISSN: 2321–4902
IJCS 2018; 6(3): 77-81

Received: 05-03-2018
Accepted: 08-04-2018

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Scenario of insect pests under changing climatic situations

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Abstract
Climate change refers to a change of climate that is attributed directly or indirectly by human activity that alters the composition of the global atmosphere and climate variability observed over comparable time period. Over past hundred years, the global temperature has increased by 0.80 °C and is expected to reach 1.1-5.4 ^{0}C by the end of next century. On the other hand, CO_2 concentration in the atmosphere has increased drastically from 280 ppm to 370 ppm and is likely to be doubled in 2100. This change is attributed mainly to the overexploitation and misuse of natural resources for various anthropogenic developmental activities such as increased urbanization, deforestation and industrialization resulting in aberrant weather events like changes in rainfall patterns, frequent droughts and floods, increased intensity and frequency of heat and cold waves. Climate change has been found to bring a number of changes in the insect phenology, distribution, species interactions, biodiversity. Other effects caused by climate change on insects include increase in number of generations, changes in crop pest synchrony, increased over wintering, invasion by migrants, decreasing effectiveness of pest management strategies. The impact of climate change can be positive, negative or neutral, since these changes can decrease, increase or have no impact on insect pests, depending on specific location of each region or period. Temperature affects the larval developmental time, larval survival and adult reproduction depending on the combination of mean temperature and magnitude of fluctuations. Therefore, there is a need to generate information on the likely effects of climate change on insect pests to develop robust technologies that will be effective in future under global warming and climate change.

Keywords: Climate change, insects, temperature, CO_2 concentration, plants

Introduction
Climate is a measure of the average pattern of variation in temperature, humidity, atmospheric pressure, wind, precipitation, atmospheric particle count and other meteorological variables in a given region over long periods of time. Climate change refers to a change of climate that is attributed directly or indirectly by human activity that alters the composition of the global atmosphere and climate variability observed over comparable time periods. In recent decades, climate change resultant global warming has become issue of serious concern worldwide for existence of life on the earth. Over past hundred years, the global temperature has increased by 0.8^{0}C and is expected to reach 1.1-5.4 ^{0}C by the end of next century (Sharma *et al.*, 2010) [33]. On the other hand, CO_2 concentration in the atmosphere has increased drastically from 280 ppm to 370 ppm and is likely to be doubled in 2100. (Heagle, 2000) [16]. This change is attributed mainly to the overexploitation and misuse of natural resources for various anthropogenic developmental activities such as increased urbanization, deforestation and industrialization resulting in aberrant weather events like changes in rainfall patterns, 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 the human beings.

How insects respond to global warming
Insects are among the groups of organisms most likely to be affected by climate change because climate has a strong direct influence on their development, reproduction, and survival. Insects respond to global warming by bringing a number of changes among themselves.

Phonological changes
Phenological changes are probably the best documented responses to recent climate change And have been detected for a wide range of organisms from plants to vertebrates

Under a rise in temperature insects will pass through their larval stages faster and will become adults earlier. Thus, observed responses include both an advance in the timing of adult emergence and an increase in the length of the flight period. Changes in butterfly phenology have been reported in the UK (Roy and Sparks, 2000) [30], with species advancing their flight periods by around 2–10 days for every 1ºC increase in temperature. This has resulted in an extended flight period, especially for multi voltine species.

Distributional shifts

Global warming is expected to force species to shift their distributions by expanding into the new climatic areas and by disappearing from areas that have become climatically unsuitable (Hughes, 2000) [16]. Shifts in distributions will occur, in part, by range expansion at the cool, upper altitudinal and latitudinal limits, and by contractions at the warm, lower altitudinal and latitudinal limits of species ranges.

Changes in species interactions

The observed changes in phenological patterns and distributions of individual species are likely to have altered species interactions within communities. As the magnitude of response differs between species the potential for disruption of existing species interactions is huge (Visser and Lambrechts, 2004) [38]. Interactions that involve two or more trophic groups, such as plant-herbivore, plant-pollinator and host-parasitic interactions are likely to suffer the largest mismatch.

Changes in biodiversity

Distributional shifts that occur as a result of climate change will also affect biodiversity. A good example of how climate change is affecting biodiversity and community composition is provided by Menendez *et al.* (2006) [22]. Sixty-five percent of the butterfly species found in Britain reach their northern limit in this region and they have responded differently to climate change. The average species richness of butterflies in Britain has increased since 1970, during a period when climate warming would lead us to expect increases. Species richness of butterflies across Britain is determined by both climate and habitat variables (host-plant richness and habitat diversity) but the relative contribution of these factors differ between habitat specialist and habitat generalist butterflies (Menendez *et al.*, 2007) [21]

Species extinctions

It has been suggested that climate change will become a major factor involved in species extinction (Thomas *et al*., 2004) [36]. Mountain species and those restricted to high latitudes will be most likely to go extinct as a result of warming. These species are adapted to cold conditions so they will be forced to move uphill and to higher latitudes as the climate warms. But, even if they are able to move, they will eventually run out of habitable areas and will inevitably go extinct.

Possible impacts of climate change on insects

Expansion of geographic ranges

The geographic distribution and abundance of plants and animals in nature is determined by species specific climate requirements essential for their growth, survival and reproduction. With rise in temperature, the insect-pests are expected to extend their geographic range from tropics and subtropics to temperate regions at higher altitudes along with shifts in cultivation areas of their host plant. (Sharma *et al*., 2010) [33] Global warming resultant altitudes wise range expansion and increased overwintering survival of corn earworms *Heliothis zea* (Boddie) and *Helicoverpa armigera* (Hubner) may cause heavy yield loss and put forth major challenge for pest management in maize, a staple food crop of USA (Diffenbaugh *et al*., 2008) [9]

Increased overwintering survival

Insects undergoing a winter diapause are likely to experience the most significant changes in their thermal environment (Bale and Hayward, 2010) [3].Accelerated metabolic rates at higher temperatures shorten the duration of insect diapause due to faster depletion of stored nutrient resources (Hahn and Denlinger, 2007) [13].Warming in winter may cause delay in onset and early summer may lead to faster termination of diapause in insects, which can then resume their active growth and development.

Increase in number of generations

As stated earlier the temperature being the single most important regulating factor for insects global increase in temperature within certain favorable range 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 (Petzoldt and Seaman, 2010) [26]

Risk of introducing invasive alien species

Changes in abiotic and/or biotic components of the environment are recognized as primary factors for the introduction of alien species. In higher altitudes, there will be rise in temperature, new species will invade these areas, which were not earlier present.

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 (Rhoades, 1985) [28].

Increased incidence of insect vectored plant diseases

Climate change may lead to more incidence of insect transmitted plant diseases through range expansion and rapid multiplication of insect vectors (Sharma *et al.,* 2010)[33].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.

Reduced effectiveness of transgenic crops for pest management

Environmental factors such as soil moisture, soil fertility, and Temperature have strong influence on the expression of *Bacillus thuringiensis* (Bt) toxin proteins deployed in transgenic plants (Sachs *et al*., 1998) [31]. Cotton bollworm, *Heliothis virescens* (F.) destroyed Bt-transgenic cottons due to high temperatures in Texas, USA.Cry1Ac levels in transgenic plants decrease with the plant age, resulting in greater susceptibility of the crop to insect pests during the later stages of crop growth (Kranthi *et al*., 2005) [20]. Possible causes for the failure of insect control in transgenic crops may be due to inadequate production of the toxin protein, effect of environment on transgene expression, Bt-resistant insect populations, and development of resistance due to inadequate management. It is therefore important to understand the effects of climate change on the efficacy of transgenic plants for pest management.

Reduced effectiveness of pest management strategies

Certain effective cultural pest management practices like crop rotation, early/ late planting, etc. will be less or no effective with changed climate because of shrinking of crop growing seasons, colonization of crops by early insect arrival and or increased winter survival. Disruption of synchrony between insect-pests and their natural enemies may upset the natural biological control. Certain pesticides like pyrethroids, organophosphates and especially the bio pesticides being highly thermo-unstable degrade faster at higher temperatures. Altered temperature regimes may render many of these products to be less or no effective in pest control, necessitating frequent insecticide applications for effective control. This may intensify the pest problems due to the increased chances of resistance development in insects. Ultimately it will add to increased cost of crop protection to the farmers and in turn environmental cost. (Petzoldt and Seaman, 2010) [26].

Effect on the activity and abundance of natural enemies

Relationships between insect pests and their natural enemies will change as a result of global warming, resulting in both increases and decreases in the status of individual pest species. Changes in interspecific interactions could also alter the effectiveness of natural enemies for pest management. Oriental armyworm, *Mythimna separata* (Walk.) populations increase during extended periods of drought (which is detrimental to the natural enemies), followed by heavy rainfall because of the adverse effects of drought on the activity and abundance of the natural enemies of this pest (Sharma *et al.*, 2010) [33]. Aphid abundance increases with an increase in CO_2 and temperature, however, the parasitism rates remain unchanged in elevated CO_2. Temperatures up to 25°C will enhance the control of aphids by coccinellids. Temperature not only affects the rate of insect development, but also has a profound effect on fecundity and sex ratio of parasitoids. The interactions between insect pests and their natural enemies need to be studied carefully to devise appropriate methods for using natural enemies in pest management.

Table 1: Insect outbreaks in relation to climate change

Insect pest	Order/ Family	Host plants	Region/ location	Probable reason/ s	Impact of pest outbreak	Reference
sugarcane woolly aphid *Ceratovacuna lanigera Zehntner*	Hemiptera: Aphididae	Sugarcane	Sugarcane belt of Karnataka and Maharashtra States during 2002-03	Recent abnormal weather patterns Insecticide misuse	30% yield losses Reduced cane recovery	Joshi, and Viraktamath, 2004; Srikanth, 2007
Rice plant hoppers *Nilparvata lugens* (Stal) and *Sogatella furcifera* (Horvath)	Hemiptera: Fulgoridae	Rice	North India	- do-	Crop failure over more than 33,000 ha paddy area	IARI News, 2008 IRRI News, 2009
Mealybug, *Phenacoccus solenopsis* Tinsley	Pseudococcidae	Cotton, Vegetables and ornamentals	Cotton growing belt of the country	Recent abnormal weather patterns, Insecticide misuse, Changed cropping environment (introduction of Bt cotton)	Heavy yield (30-40%) loss to the cotton Increased cost of crop protection due to overuse of pesticides	Dhawan *et al*., 2007
Papaya mealybug *Paracoccus marginatus*	Hemiptera: Pseudococcidae	Papaya	Tamil Nadu, Karnataka, Maharashtra	Recent abnormal weather patterns Insecticide misuse	Significant yield loss to the papaya growers	Tanwar *et al*., 2010

Effect of elevated CO2 on insects

The expected concentration of CO2 in the year of 2100 ranges from 540 to 970 ppm compared to about 280 ppm in the pre-industrial era and changes in plant quality due to elevated CO2 may affect herbivory patterns and insect richness, abundance and/ or diversity.

Elevated CO2 Concentrations cause following effects

- Enhanced photosynthetic activity
- Increasing leaf area and productivity
- Increasing carbon content in plant, reducing nitrogen content
- Decreasing formation of nitrogen based defense chemicals in the plant like alkaloids
- Reducing the water loss through the plants.

Effect of Elevated Carbon Dioxide on Crop Pest Dynamics

A larger crop canopy and denser foliage resulted from enhanced CO2 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) [5]. Some more findings on effects of enhanced CO2 on crop pests is given in the Table 2.

Table 2: 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 Lndrot1995
Effect of transgenic *B. thuringiensis*	Coviella *et al*., 2000
Nitrogen-based plant defense	Coviella and Trumble, 1999

Table 3: Pest complex under elevated CO_2 concentrations:

Insects	Elevated CO2	References
Japanese beetlePotato leaf hopper Western corn root wormMexican bean beetle	57% more damage	Trumble and Butler,2009
Thrips	90% more feeding	Heagle,2003
Cereal Aphids	Higher population	Newman,2004

Under elevated CO_2 concentrations, nutritional quality of the plant is reduced due to reduced nitrogen contents.As a result of which insect consumes more and more food to fulfill its nutritional requirements.

Increasing CO_2 concentration causes following effects
In plant
Increasing carbon content
Increasing C: N ratio
Decreasing nitrogen
Increasing food consumption by insect

In insect
Increase larval weight
Increase developmental time (Larval duration)
Increasing amount of fecal matter produced by insect

Effect of Fluctuating Temperature on Insects
Temperature influences insect
- Behavior
- Distribution
- Development
- Survival and Reproduction

Table 4: 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

Impact of precipitation/ Drought on insects
Large scale changes in rainfall will have a major effect on the abundance and diversity of arthropods. 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. Some insects e.g. onion thrips are sensitive to precipitation and are killed or removed from crops by heavy rains. For some insects that overwinter in soil, flooding the soil has been used as a control measures.Decreasing snowfall promotes the expansion of pine moth, *Thaumetopoea pityocampa* into high elevation stands of mountain pine. More than 50 species of butterflies showed northward range expansions and 10 species of previously migrant butterflies have been established on Nansei Islands during 1966 to 1987. Droughts are likely to decrease multi-trophic diversity and change the composition of arthropod communities which in turn might affect the other associated taxa. Enhanced summer rainfall and drought conditions promote rapid increase in the population of wireworm (*Agriotes lineatus)* in the upper soil. Drought conditions severely affect egg viability of *Scopelosaurus lepidus* eggs and did not hatch at all under dry conditions. High humidity favours some insects such as aphids. Thrips and whiteflies are sensitive to precipitation and are removed or killed by heavy rains. Outbreak of *Amsacta moorie* are directly related to heavy and frequent rains.

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