Impact of Climate Change on Pest Management and Food Security

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2.1 Introduction

The last decade of the 20th century and the first decade of the 21st century have been the warmest periods in the entire global temperature record. The Intergovernmental Panel on Climate Change (IPCC, 2001) has concluded that most of the global warming observed over the last 50 years is attributable to human activities. Climate change, as described by IPCC, refers to '*a change in the state of the climate that can be identified (by using statistical tests) by changes in the mean and/or the variability of its properties that persists for an extended period, typically for decades or longer. It refers to any change in climate over time, whether due to natural variability or as a result of human activity*' (IPCC, 2007). The rise in global climate temperature is mostly due to increased concentrations of greenhouse gases, which include carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O) and chlorofluorocarbons (CFCs). Over the past 200 years, the atmospheric concentration of carbon dioxide has increased by 35%, and is expected to double by the end of this century, i.e. 280ppm in the preindustrial era vs. 360ppm at present (Houghton et al., 1995). The global mean surface temperature rose by 0.6 ± 0.2°C during 20th century, and climatic models have predicted an average increase in global temperature of 1.8°C to 4°C over the next 100 years (Collins et al., 2007; Johansen, 2002; Karl and Trenbeth, 2003). The IPCC suggested that if temperatures rise by about 2°C over the next 100 years, negative effects of global warming would begin to extend to most regions of the world, and affect most of the living organisms including humans and plants. Climatic variables such as temperature, rainfall, humidity, and atmospheric gases interact with plants in numerous ways with diverse mechanisms. These changes are affecting plants directly in terms of tissue and organ-specific photosynthetic allocation, and indirectly through change in geographic distribution and population dynamics of the pest species. Experiments have indicated that higher levels of CO2 generally increase productivity of crop plants (Fuhrer, 2003; Long et al., 2004), as elevated CO2 increases the photosynthetic rates (Drake et al., 1997; Norby et

al., 1999) and biomass production (Curtis and Wang, 1998; Ledley et al., 1999). However, increase in crop production may be offset through high temperatures and reduced water availability. Global warming and climate changes are having a negative impact on the productivity of cereals and other crops (Anwar et al., 2007; Challinor et al., 2005; Choudhary et al., 2012; Torriani et al., 2007). Increased temperature will cause insect pests to become more abundant (Bale et al., 2002; Cannon, 1998; Patterson et al., 1999) and almost all insects will be affected by changes in temperature. Porter et al. (1991) listed various effects of temperature on insects, including: limitation of geographical range, overwintering, population growth rates, number of generations per annum, crop–pest synchronization, dispersal and migration, and availability of host plants and refugia. Laboratory and modelling experiments with increased temperature support the perception that the biology of agricultural pests is likely to be affected by global warming (Cammell and Knight, 1992; Fleming and Volney, 1995; Fye and McAda, 1972). For example, warming could decrease the occurrence of severe cold events (Diffenbaugh et al., 2005), which in turn might expand the overwintering area for insect pests (Patterson et al., 1999). In-season effects of warming include the potential for increased levels of feeding and growth, including the possibility of additional generations in a given year (Cannon, 1998). This will alter the crop yield, and also influence the effectiveness of insect-pest management practices. Increased global temperature will also influence the phenology of insects including early arrival of insect pests in their agricultural habitats and emergence time of a range of insect pests (Dewar and Watt, 1992; Whittaker and Tribe, 1996, 1998). This will require early and more frequent application of insecticides to reduce the pest damage. Increased temperatures will also increase the pest population, and water stressed plants at times may result in increased insect populations and pest outbreaks. This will affect the crop yield and availability of food grains and threaten food security. Temperature increases associated with climatic changes could result in:

- change in geographical range of insect pests,
- increased overwintering and rapid population growth,
- changes in insect–host plant–natural enemy interactions,
- impact on arthropod diversity and extinction of species,
- changes in synchrony between insect pests and their crop hosts,

● introduction of alternative hosts as green bridges,

● changes in relative abundance and effectiveness of biocontrol agents,

● change in expression of resistance to insects in cultivars with temperature-sensitive genes,

● emergence of new pest problems and increased risk of invasion by migrant pests, and

● reduced efficacy of different components of insect-pest management.

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. Long-term monitoring of population levels and insect behaviour, particularly in identifiably sensitive regions, may provide some of the first indications of a biological response to climate change. The impact of climate change will vary across regions, crops and species. A large number of models and protocols have been designed to measure the effects of climate change for different species and in different disciplines. There is a need for interdisciplinary cooperation to measure the effects of climate change on the environment and food security. It will be important to keep ahead of undesirable pest adaptations, and consider global warming and climate change for planning research and development efforts for integrated pest management (IPM) in the future.

2.2 Impact of climate change on geographic distribution and population dynamics of insect pests

Present and future change in climate will have a significant bearing on the biology and behaviour of insects as insects are poikilothermic (cold-blooded) organisms, and are particularly sensitive to temperature changes. This will change the distribution and severity of infestation of crops through direct effects on the life cycle of insects, and indirectly through climatic effects on hosts, natural enemies, competitors, and insect pathogens (Cammell and Knight, 1992; Dobzhansky, 1965; Fye and McAda, 1972; Harrington and Stork, 1995; Kingsolver, 1989; Mattson and Haack, 1987; Tauber et al., 1986). Low temperatures are often more important than high temperatures in determining the geographical distribution of insect pests (Hill, 1987). Increasing temperatures may result in a greater ability to overwinter in insect species limited by low temperatures at

higher latitudes (EPA, 1989; Hill and Dymock, 1989). Recent reports have indicated that the distribution of insects is intensifying at high latitudes and high elevations (Anderson et al., 2008; Hickling et al., 2006; Parmesan and Yohe, 2003; Parmesan et al., 1999; Warren et al., 2001) and diminishing at their low latitudes and low elevations and hightemperature margins (Anderson et al., 2008; Franco et al., 2006; Parmesan, 1996; Wilson et al., 2007). Insect species richness is increasing in cool habitats (Andrew and Hughes, 2005a,b). Butterfly species in the UK are decreasing most rapidly in the south, while species with a southerly distribution are expanding northwards (Breed et al., 2013; Conrad et al., 2004). There is also some evidence that the risk of crop loss will increase due to pole-ward and high-elevation expansion of insect geographical ranges (Bjorkman et al., 2011; Wolf et al., 2008). For all of the insect species, higher temperatures, below the species' upper threshold limit, will result in faster development, resulting in rapid increase in pest populations as the time to reproductive maturity is reduced, and species characterized by high reproduction rates being generally favoured (Southwood and Comins, 1976). Temperature limits geographical range, overwintering, population growth rates, length of crop growing season, crop-pest synchronization, interspecific interactions, dispersal and migration and availability of host plants (Porter et al., 1991). Spatial shifts in the distribution of crops will also influence the distribution of insect pests (Parry and Carter, 1989). However, whether or not an insect species would move with a crop into the new habitats will also depend on the presence of overwintering sites, soil type, and moisture; e.g. corn earworm, *Heliothis zea* (Boddie) might move to higher latitudes/altitudes in North America, leading to greater damage in maize and other crops (EPA, 1989).

Global warming will lead to earlier infestation by *H. zea* in North America (EPA, 1989), and *Helicoverpa armigera* (Hubner) in North India (Sharma, 2010), resulting in increased crop loss. Rising temperatures are likely to result in availability of new niches for insect pests. Temperature has a strong influence on the viability and incubation period of *H. armigera* eggs (Dhillon and Sharma, 2007). Egg incubation period can be predicted based on egg age and storage temperature, and the degreedays required for egg hatching decreased with an increase in temperature from 10 to 27°C, and egg age from 0 to 3 days (Dhillon and Sharma, 2007). An increase of 3°C in mean daily temperature would cause the carrot fly, *Delia radicum* (L.), to become active a month earlier than at present (Collier et al., 1991),

and temperature increases of 5 to 10°C would result in completion of four generations each year, necessitating adoption of new pest control strategies. An increase of 2°C will reduce the generation turnover of the bird cherry aphid, *Rhopalosiphum padi* (L.), by varying levels, depending on the changes in mean temperature (Morgan, 1996). An increase of 1 and 3°C in temperature will cause northward shifts in the potential distribution of the European corn borer, *Ostrinia nubilalis* (Hubner), of up to 1220km, with an additional generation in nearly all of the regions (Porter et al., 1991). Cottony cushion scale, *Icerya purchasi* Maskell, populations appear to be spreading northwards perhaps as a consequence of global warming; and cottony camellia scale, *Chloropulvinaria floccifera* (West.), has become much more common in the UK, extending its range northwards, and increasing its host range in the last decade in response to climate change. In Sweden, this species was previously only known as a greenhouse species, but is now established as an outdoor species. Warming will allow the cold intolerant pink bollworm, *Pectinophora gossypiella* (Saunders), to expand its range on cotton into formerly inhospitable areas affected by heavy frosts, and damage rates will increase throughout its current range (Gutierrez et al., 2006, 2008). The survival of palm thrips, *Thrips palmi* Karny, is currently limited in the UK due to lack of cold tolerance, but this species may spread to other area in future (McDonald et al., 2000). Fruit flies, *Bactrocera tryoni* (Froggatt), *Bactrocera cucurbitae* (Coquillett) and *Bactrocera latifrons* (Hendel), may be spread into colder areas due to increasing temperature (Prabhakar et al., 2012a,b; Sutherst, 1991; Sutherst et al., 2007). The increased movements of warm air towards high latitudes have caused recent arrivals of diamondback moth, *Plutella xylostella* (L.), on the Norwegian islands of Svalbard in the Arctic Ocean, 800 km north of the edge of its current distribution in the western Russian Federation (Coulson et al., 2002). For a 3°C temperature increase in Japan, Mochida (1991) predicted expanded ranges for tobacco cutworm, *Spodoptera litura* (F.), southern green stink bug, *Nezara viridula* (L.), rice stink bug, *Lagynotomus elongatus* (Dallas), Lima-bean pod borer, *Etiella zinckenella* (Treitschke), common green stink bug, *Nezara antennata* Scott, soybean stem gall midge, *Asphondylia* sp., rice weevil, *Sitophilus oryzae* (L.), and soybean pod borer, *Leguminivora glycinivorella* (Matsumura), but a decreased range for rice leaf beetle, *Oulema oryzae* (Kuwayama), and rice leaf miner, *Agromyza oryzae* (Manukata).

Overwintering of insect pests will increase as a result of climate change, producing larger spring populations as a base for build-up in numbers in the following season. These may be vulnerable to parasitoids and predators if the latter also overwinter more readily. Diamondback moth, *P. xylostella*, overwintered in Alberta (Dosdall, 1994), and if overwintering becomes common, the status of this insect pest will increase dramatically. There will also be increased dispersal of airborne insect species in response to atmospheric disturbances. Many insect species such as *H. armigera* and *H. zea* are migratory, and, therefore, may be well adapted to exploit new opportunities by moving into new areas as a result of climate change (Sharma, 2005). The effects of precipitation vary with the species as some insects are sensitive to precipitation and are killed or removed from crops by heavy rains, e.g. onion thrips (Reiners and Petzoldt, 2005), cranberry fruit worm and other cranberry insect pests (Vincent et al., 2003). Precipitation has a positive effect on pea aphid (McVean et al., 1999). However, under elevated CO2 and O3 in the future, some of the insects may be unaffected as there was no effect on development time, adult weight, embryo number and the weight of nymphs of the aphid, *Cepegillettea betulaefoliae* Granovsky, feeding on paper birch (Awmack et al., 2004).

2.3 Effect of climate change on the effectiveness of pest management technologies

2.3.1 Expression of Resistance to Insect Pests

Host-plant resistance to insects is one of the most environmentally friendly components of pest management. However, climate change may alter the interactions between insect pests and their host plants (Sharma et al., 2010). Resistance to sorghum midge, *Stenodiplosis sorghicola* (Coq.), observed in India, breaks down under high humidity and moderate temperatures in Kenya (Sharma et al., 1999). Sorghum midge damage in the midge-resistant lines ICSV 197, TAM 2566 and AF 28 decreased with an increase in open pan evaporation, maximum and minimum temperatures, and solar radiation, while no significant effect was observed on the susceptible cultivars ICSV 112 and CSH 5 (Sharma et al., 2003). There will be an increased impact on insect pests which benefit from reduced host defences as a result of the stress caused by the lack of adaptation to suboptimal climatic conditions. Some plants can change their chemical composition in direct response to insect damage to make their tissues less suitable for growth and survival of insect pests

(Sharma, 2002). Generally, CO2 impacts on insects are thought to be indirect. Impact on insect damage will result from changes in nutritional quality and secondary metabolites of the host plants. Increased levels of CO2 will enhance plant growth, but may also increase the damage caused by some phytophagous insects. In the enriched CO2 atmosphere expected in the 21st century, many species of herbivorous insects will confront less nutritious host plants that will induce both lengthened larval developmental times and greater mortality (Coviella and Trumble, 1999). The effects of climate change on the magnitude of herbivory and direction of response will not only be species-specific, but also specific to each insect–plant system. Bark beetles, wood borers, and sap sucking insects benefit from severe drought (Bjorkman and Larsson, 1999; Huberty and Denno, 2004; Koricheva et al., 1998), while *Spodoptera exigua* (Hub.) exhibited a reduced ability to feed on drought-stressed tomato leaf tissue, which contained higher levels of defence compounds as a result of the abiotic stress (English-Loeb et al., 1997). Severe drought increases the damage by insect species such as spotted stem borer, *Chilo partellus* (Swinhoe), in sorghum (Sharma et al., 2005) and litchi stink bug, *Tessaratoma javanica* (Thunberg), in litchi (Choudhary et al., 2013). However, the effect of drought on leaf miners, leaf defoliators, and gall makers is more uncertain (Jactel et al., 2012). Although increased CO2 tends to enhance plant growth rates, the greater effects of increased drought stress will probably result in slower plant growth (Coley and Markham, 1998). In atmospheres experimentally enriched with CO2, the nutritional quality of leaves declined substantially due to a dilution of nitrogen by 10–30% (Coley and Markham, 1998).

Increased CO2 may also cause a slight decrease in nitrogen-based defences (e.g. alkaloids) and a slight increase in carbon-based defences (e.g. tannins). Lower foliar nitrogen due to CO2 causes an increase in food consumption by herbivores. Soybeans grown in elevated CO2 suffered 57% more damage from herbivores (primarily Japanese beetle, potato leafhopper, western corn rootworm and Mexican bean beetle) than those grown in ambient CO2. Increase in amounts of simple sugars and down-regulation of gene expression for a protease-specific deterrent to coleopteran herbivores may have resulted in greater insect feeding (Hamilton et al., 2005; Zavala et al., 2008). Elevated CO2 decreases the induction of jasmonic acid and ethylene related transcripts (*lox7*, *aos*, *hpl*, and *acc1*) in soybean plants causing decreased accumulation of defences (polyphenol oxidase, protease inhibitors, etc.)

over time compared to plants grown under ambient conditions, suggesting that CO2 exposure might have resulted in increased insect damage (Casteel, 2010). Problems with new insect pests will occur if climatic changes favour the introduction of nonresistant crops or cultivars into new areas. The introduction of new crops and cultivars could be one of the methods to take advantage of climate change (Parry, 1990; Parry and Carter, 1989).

2.3.2 Transgenic Crops for Pest Management

Transgenic cotton plants expressing the *Bacillus thuringiensis* (*Bt*) (Berliner) insecticidal protein showed a reduction in the level of toxin protein during periods of high temperature, elevated CO2 levels, or drought, leading to decreased resistance to insect pests (Chen D.H. et al., 2005; Chen F.J. et al., 2005a; Dong and Li, 2007). Cotton bollworm, *Heliothis virescens* (F.), destroyed *Bt* cottons due to high temperatures in Texas, USA (Kaiser, 1996). Similarly, *H. armigera* and *H. punctigera* damaged *Bt*-cotton in the second half of the growing season in Australia because of reduced production of *Bt* toxins in the transgenic crops (Hilder and Boulter, 1999). Cry1Ac levels decrease with plant age, resulting in greater susceptibility of the crop to bollworms during the later stages of crop growth (Adamczyk et al., 2001; Greenplate et al., 2000; Kranthi et al., 2005; Sachs et al., 1998; Sharma, unpublished data). Possible causes for the failure of insect control may be due to inadequate production of the toxin protein, the effect of environment on transgene expression, locally resistant insect populations, and development of resistance due to inadequate management (Sharma and Ortiz, 2000). It is therefore important to understand the effects of climate change on the efficacy of transgenic plants for pest management.

2.3.3 Activity and Abundance of Natural Enemies

The majority of insects are benign to agroecosystems, and there is much evidence to suggest that this is due to population control through interspecific interactions among insect pests and their natural enemies – pathogens, parasites, and predators (Price, 1987). Increases in atmospheric CO2, low precipitation and increases in temperature will alter plant phenology, influencing herbivore growth and abundance, and indirectly affecting the abundance of prey and insect hosts for natural enemies (Thomson et al., 2010). Relationships between insect pests and their natural enemies will change as a result of

climate change, resulting in both increases and decreases in the status of individual pest species. Changes in temperature will also alter the timing of diurnal activity patterns of different groups of insects (Young, 1982), and changes in interspecific interactions could also alter the effectiveness of natural enemies for pest management (Hill and Dymock, 1989). The fitness of natural enemies will decline as the quality of their herbivore hosts decreases (Wang et al., 2007) as has been shown for several groups of predators including spiders (Hvam and Toft, 2005; Toft, 1995), predatory bugs (Butler and O'Neil, 2007) and carabid beetles (Bilde and Toft, 1999). However, a decrease in prey size will not necessarily always lead to a reduction in the success of predators. The number of prey consumed by predators might increase and lead to improved pest control (Chen F.J. et al., 2005b; Coll and Hughes, 2008). For example, the coccinellid predator, *Leis axyridis* Pallas, of cotton aphid, *Aphis gossypii* Glover, consumed more prey under higher CO2 (Chen F.J. et al., 2005b). The pentatomid bug, *Oechalia schellenbergii* GuerinMeneville, exhibited increased predation of cotton bollworm, *H. armigera*, feeding on peas under elevated CO2 because the pea plants had reduced nitrogen content when grown under high CO2, which influenced the size of the cotton bollworm larvae (Coll and Hughes, 2008), whereas a negligible effect was observed in the interactions between *Harmonia axyridis* (Pallas) and its aphid host, *Sitobion avenae* F. (Chen et al., 2007). Quality of insect hosts may also affect parasitoid fitness (Wang et al., 2007), particularly in parasitoids whose hosts continue to feed after parasitization as fecundity of the parasitoid is positively correlated with size and host quality (Harvey et al., 1999). However, increased abundance of the braconid parasitoid, *Aphidius picipes* (Nees), was recorded on *Sitobion avenae* F. parasitism under elevated CO2 compared to the insects raised under ambient CO2 (Chen et al., 2007). The oriental armyworm, *Mythimna separata* (Walker), population increases during extended periods of drought (which is detrimental to the natural enemies), followed by heavy rainfall (Sharma et al., 2002). In cassava, parasitism of mealy bugs is reduced under conditions of water stress associated with drought due to improved immune response of mealy bugs on water stressed plants, leading to an increased rate of encapsulation (Calatayud et al., 2002). Apart from surviving thermal extremes, natural enemies will also need to counter climate change by mating and locating hosts effectively across a wider range of thermal and humidity conditions. Even small changes in thermal conditions might influence the effectiveness of parasitoids in

controlling insect pests. Temperatures up to 25°C will enhance the natural control of aphids by coccinellids (Freier and Triltsch, 1996). Temperature not only affects the rate of insect development, but also has a profound effect on fecundity, sex ratio and host location by the parasitoids (Dhillon and Sharma, 2008, 2009; Thomson et al., 2010). Host location of the egg parasitoid, *Trichogramma carverae* Oatman and Pinto, decreases sharply at temperatures above 35°C (Thomson et al., 2001), while fecundity reductions of up to 50% are commonly observed at temperatures >30°C (Naranjo, 1993; Scott et al., 1997). 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 programmes under changed climate.

2.3.4 Biopesticides and Synthetic Insecticides

There will be an increased variability in insect damage as a result of climate change. Higher temperatures will make dry seasons drier, and conversely, may increase the amount and intensity of rainfall, making wet seasons wetter than at present. Current sensitivities on environmental pollution, human health hazards, and, pest resurgence are a consequence of improper use of synthetic insecticides. Natural plant products, entomopathogenic viruses, fungi, bacteria, nematodes, and synthetic pesticides are highly sensitive to the environment. Temperature is a major factor affecting insecticide toxicity (DeVries and Georghiou, 1979), and, thus, efficacy (Johnson, 1990; Scott, 1995). The effects of temperature on efficacy can be either positive or negative. The response relationship between temperature and efficacy has been found to vary depending on the mode of action of an insecticide, target species, method of application, and quantity of insecticide ingested or contacted (Johnson, 1990). Increased temperature will increase the activity of some of the insecticides. Diflubenzuron (an insect growth regulator (IGR)) caused rapid mortality at higher temperatures and was more efficient at 35°C (Amarasekare and Edelson, 2004). This was probably because this IGR is only effective when the insect moults (Ware, 2000), and the insect growth rate and moulting rate increase at higher temperatures (Lactin and Johnson, 1995). However, the biological activity of the entomopathogenic fungus, *Beauveria bassiana* (Balsamo), is reduced at temperatures >25°C (Amarasekare and Edelson, 2004; Inglis et al., 1999). Increase in temperature and UV radiation, and a decrease in relative

humidity, may render many of the pest control tactics to be less effective, and such an effect will be more pronounced on natural plant products and the biopesticides. Entomopathogens used as biocontrol agents suffer from instability after exposure to solar radiation, especially in the ultraviolet (UV) portion of the spectrum (Bullock, 1967; Jaques, 1968; Morris, 1971; Timans, 1982). Several studies have reported a significant decrease in biological activity of entomopathogens, viz. NPV, GV, *Beauveria* and *Bt* (up to 90%) within a few days (Broome et al., 1974; David et al., 1968; Ignoffo et al., 1977; Jones and McKinley, 1986). Another effect of increased temperature and UV radiation may be to slow down the activity even without the loss of activity due to UV radiation; as a result, more time may be required to achieve insect mortality (Moscardi, 1999; Szewczyk et al., 2006). Larvae continue to feed and damage crops until shortly before death. Chen and McCarl (2001) estimated that pest treatment costs under the 2090 projections of climate exhibit increases of 3–10% for corn, soybeans, cotton and potatoes and mixed results for wheat, and show a $200 million per year projected loss to society due to climate change related pesticide treatment cost effects in the USA. Therefore, there is a need to develop appropriate strategies for pest management that will be effective under situations of global warming in the future. Farmers will need a set of pest control strategies that can produce sustainable yields under climatic change.

2.4 Climate change and pest management: the challenge ahead

The greatest challenge facing humanity in this century will be the necessity to double food production to meet the demands of droughts resulting from global warming, and the increasing population, by using less land area, less water, and less soil nutrients. The effects of climate change on pest control will be complex, particularly when new crops are adopted in new areas. As a result, the herbivores will escape the natural enemies, at least temporarily. This will have a major bearing on economic thresholds, as greater variability in climate will result in variable impact of pest damage on crop production. The relationship between the input costs and the resulting benefits will change as a result of changes in plant–insect–natural enemies–environment interactions. Increased temperatures and UV radiation, and low relative humidity, may render many of these control tactics less effective, and therefore, there is a need to: (i) study insect responses to

climate change to predict and map the geographical distribution of insect pests and their natural enemies, and understand the metabolic alterations in insects in relation to climate change, (ii) investigate how climatic changes will affect development, incidence, and population dynamics of insect pests, (iii) have a fresh look at the existing economic threshold levels for each crop–pest interaction, as changed feeding habits or increased feeding under high CO2 will change the economic threshold level for the pest, (iv) study changes in expression of resistance to insect pests and identify stable sources of resistance for use in crop improvement, (v) understand the effect of global warming on the efficacy of transgenic crops in pest management, (vi) assess the efficacy of various pest management technologies under diverse environmental conditions, and (vii) develop appropriate strategies for pest management to mitigate the effects of climate change.

2.5 Conclusions

Climate change and global warming will have serious consequences for the diversity and abundance of arthropods, and the extent of losses due to insect pests, which will impact both crop production and food security. Presently, it is estimated that the amount of food that insects consume (pre- and postharvest) is sufficient to feed more than 1 billion people. By 2050, it is thought that there will be an extra 3 billion people to feed. During this timescale, it is likely that insects will increase in numbers and in pest types. Prediction of changes in geographical distribution and population dynamics of insect pests will be useful for adapting IPM strategies to mitigate the adverse effects of climate change on crop production. Pest outbreaks might occur more frequently, particularly during extended periods of drought, followed by heavy rainfall. Some of the components of pest management such as host-plant resistance, biopesticides, natural enemies, and synthetic chemicals will be rendered less effective as a result of the increase in temperatures and UV radiation, and decrease in relative humidity. Climate change will also alter the interactions between insect pests and their host plants. As result, some of the cultivars that are resistant to insects may exhibit susceptible reactions under global warming. Adverse effects of climate change on the activity and effectiveness of natural enemies will be a major concern in future pest management programmes. The rate of insect multiplication might increase with an increase in CO2 and temperature. There may be the possibility of evolutionary

adaptation in insects to the changing environment. Therefore, climate change might change the population dynamics of insect pests differently in different agro-ecosystem and ecological zones. 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.

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