Climate Change *vis-a-vis* Pest Management

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Abstract: *Global warming and climate change will trigger major changes in geographical distribution and population dynamics of insect pests, insect – host plant interactions, activity and abundance of natural enemies, and efficacy of crop protection technologies. Changes in geographical distribution and incidence will affect both crop production and food security. Insect pests presently confined to tropical and subtropical regions will move to temperate regions along with a shift in the areas of cultivation 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. The relative efficacy of pest control measures such as host-plant resistance, natural enemies, bio-pesticides, and synthetic chemicals is likely to change as a result of global warming and climate change. There is an urgent need to assess the efficacy of various pest management technologies under diverse environmental conditions, and develop appropriate strategies for pest management to mitigate the adverse effects of climate change.*

Introduction

Insect pests cause an estimated annual loss of 13.6% globally, and the extent of losses in India has been estimated to be 17.5% (Dhaliwal et al., 2010). The pest associated losses likely to increase as a result of changes in crop diversity and climate change, and changes in the cropping patterns and the cropping intensity (Table 1). Pest associated losses increased from an average of 7.2% during the pre-green revolution period to 23.3% during the post green revolution period in different crops in India. Climate change and climate variability will have major implication for water availability forest cover, biodiversity, crop production, and food security.

Changes in rainfall pattern are of greater importance for agriculture than the annual changes in temperature, especially in regions where lack of rainfall may be a limiting factor for crop production. Geographical distribution of tropical and subtropical insect pests will extend along with shifts in the areas of cultivation of their host plants, while distribution and relative abundance of some insect species vulnerable to high temperatures in the temperate regions may decrease. High mobility and rapid population growth will increase the extent of losses due to insect pests. Current 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, and the date at which an equivalent doubling of CO_2 will be attained is estimated to be between 2025 and 2070, depending on the level of emission of greenhouse gasses (IPCC 1990; Crowley 2000). Mean annual temperature changes between 3 and 6°C are estimated to occur across Europe, with greatest increases occurring at high latitudes.

Climate change and emerging pest problems in India

Several insect pests, that were important in the past or the minor pests, are likely to become more devastating with global warming and climate change (Sharma 2013) (Fig 1, Table 2). Many insect species, that will move to newer areas as invasive pests will also pose a major threat to crop production and food security, as they find more suitable climatic niches in the new areas. The invasive species are likely to cause more harm in the absence of natural enemies in the new habitats.

Table 1. Pest associated losses in different crops during the pre- and post-green revolution in India.

Crop	Pre-green revolution (early 1960s)	Post-green revolution (early 2000s)	Changes in pest associated losses
Cotton	18.0	50.0	+ 32.0
Groundnut	5.0	15.0	+ 10.0
Other oilseeds	5.0	25.0	+ 20.0
Pulses	5.0	15.0	+ 10.0
Rice	10.0	25.0	+ 15.0
Maize	5.0	25.0	+ 20.0
Sorghum and millets	3.5	30.0	+ 26.5
Wheat	3.0	5.0	+ 2.0
Sugarcane	10.0	20.0	+ 10.0
Average	7.2	23.3	+ 16.1

Source: Dhaliwal et al., (2010).

Fig 1. Pest outbreaks due to climate change (a = Pod borer, *Helicoverpa armigera* damage in pigeonpea following wet weather conditions in Sept – Oct, b = Mealy bug, *Ceroplastodes cajaninae* infestation in pigeonpea under prolonged hot and dry conditions, c = Beet armyworm, *Spodoptera exigua* damage in chickpea triggered by winter rains on Oct – Nov, and d = Pink stem borer, *Sesamia inferens* damage in sorghum due to hot and dry conditions during the postrainy season).

Table 2. Insect pests that have become or are likely to become serious pests due to climate change and changes in cropping patterns.

Insect pest	Scientific name	Crop(s)
American bollworm	*Helicoverpa armigera* (Hubner)	Cotton, chickpea, pigeonpea, sunflower, tomato, etc.
Beet armyworm	*Spodoptera exigua* (Hub.)	Chickpea in southern India
Spotted pod borer	*Maruca vitrata* (Geyer)	Pigeonpea, cowpea, lab-lab beans
Diamondback moth	*Plutella xylostella* (L.)	Cabbage, cauliflower
Pink stem borer	*Sesamia inferens* (Walk.)	Maize, sorghum, wheat
Whitefly	*Bemisia tabaci* (Gen.)	Cotton, tobacco
Brown planthopper	*Nilaparvata lugens* (Stal)	Rice
Green leafhopper	*Nephotettix* spp.	Rice
Serpentine leaf miner	*Liriomyza trifolii* (Burg.)	Cotton, tomato, cucurbits, several other vegetables
Fruit fly	*Bactrocera* spp.	Fruits and vegetables
Mealy bugs	*Paracoccus marginatus* Williams & Granara de Willink *Phenococcus solenopsis* (Tinsley) *Cerolastodes gajaninae* (Mask.)	Several field and horticultural crops
Thrips	Several species	Groundnut, cotton, chillies, citrus, pomegranate
Wheat aphid	*Macrosiphum miscanthi* (Takahashi)	Wheat, barley, oats
Pod sucking bugs	*Clavigralla* spp.	Pigeonpea
Gall midge	*Orseolia oryzae* (Wood-Mason)	Rice
Termites, white grubs,	Several species	Many crops
Sugarcane aphid	*Ceratovacuna lanigera* (Zehnt.)	Sugarcane

Based on Prasad and Bambawale (2010), Fand et al., (2012) and Sharma (2013).

Climate change effects on geographic distribution and population dynamics of insect pests

Low temperatures are often more important than high temperatures in determining geographical distribution of insect pests. Increasing temperatures may result in a greater ability to overwinter in insect species limited by low temperatures at higher latitudes, extending their geographical range (EPA 1989; Hill and Dymock 1989). Spatial shifts in distribution of crops under changing climatic conditions will also influence the distribution of insect pests in a geographical region (Parry and Carter 1989). There are several examples of change in the geographic distribution of several insect species as a result of climate change (Table 3). However, whether or not an insect pest would move with a crop into a new habitat will depend on other environmental conditions such as the presence of overwintering sites, soil type and moisture. Populations of the corn earworm [*Heliothis zea* (Boddie)] in the North America might move to higher latitudes/altitudes, leading to greater damage in maize and other crops (EPA 1989). The cotton bollworm/ legume pod borers, *H. armigera* and *M. vitrata* will move to temperate regions in northern Europe (Fig. 3). *Helicoverpa armigera* has already reached Brazil as an invasive pest, and is likely to move to North America (Czepak et al,. 2013). For all the insect species, higher temperatures, below the species' upper threshold limit, will result in faster development, resulting in rapid increase of pest populations as the time to reproductive maturity is reduced. In addition to the direct effects of temperature changes on development rates, increases in food quality due to plant stress may result in dramatic increases in growth of insect pest populations, while the growth of certain insect pests may be adversely affected (Maffei et al. 2007).

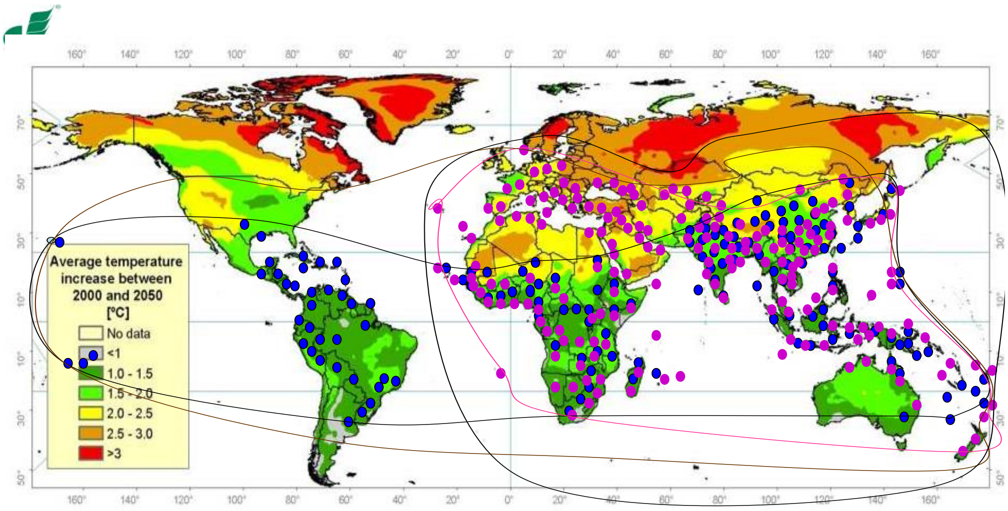

Fig 2. Likely changes in geographical distribution of cotton bollworm/legume pod borer, *Helicoverpa armigera* (red line: current, and black line likely distribution in future), and spotted pod borer, *Maruca vitrata* (blue line current, and brown line future distribution) (Sharma 2013).

Table 3. Examples of changes in geographic distribution of insect pests as a result of climate change.

Insect pest	Host plant/s	Impact on insects / behavioral response	Reference
Corn earworm, *Helicoverpa zea* (Boddie)	Maize	Range expansion to higher altitudes and northern Europe and USA, and increased overwintering	Diffenbaugh et al. (2008)
European corn borer, *Ostrinia nubilalis* (Hub.)	Maize	Northward shifts with an additional generation per season	Porter et al. (1991)
Old world Bollworm *Helicoverpa armigera*		Increased presence in southern Europe and outbreaks	Cannon (1998)
Pod borers, *Helicoverpa armigera* and *Maruca vitrata* (Geyer)	Cotton, pulses, vegetables	Expansion of geographic range in northern Asia and Europe	Sharma (2013)
Oak processionary moth, *Thaumetopoea processionea* (L.)		Northward range extension from southern Europe to Belgium, Netherlands and Denmark	Cannon (1998)
Non-migratory butterflies		Pole ward shift of geographic range	Parmesan and Yohe (2003)

Global warming and pest outbreaks

Global warming will result in pest outbreaks (Table 4). Pest outbreaks are more likely to occur with stressed plant's as a result of weakening of plants' defensive system, and thus, increasing the level of susceptibility to insect pests. Global warming will lead to earlier infestation by *H. armigera* in North India (Sharma 2010, 2013), resulting in increased crop loss. Overwintering of insect pests will increase as a result of climate change, producing larger spring populations as a base for a build-up in numbers in the following season. Many insects such as *Helicoverpa* spp. are migratory, and therefore, may be well adapted to exploit new opportunities by moving rapidly into new areas as a result of climate change (Sharma 2005).

Table 4. Recent pest outbreaks in relation to climate change in India.

Insect pest	Host plant/s	Region/ location	Probable reason/s	Impact	Reference
Sugarcane woolly aphid *Ceratovacuna lanigera*	Sugarcane	Karnataka and Maharashtra during 2002-03	Abnormal weather conditions Insecticide misuse	30% yield losses Reduced cane recovery	Joshi and Viraktamath (2004), Srikanth (2007)
Plant hoppers *Nilparvata lugens Sogatella furcifera*	Rice	North India	Abnormal weather conditions Insecticide misuse	Crop failure on >33,000 ha	IARI (2008)
Mealybug, *Phenacoccus solenopsis*	Cotton, Vegetables	Punjab, Haryana	Hot and dry weather Insecticide misuse	30-40% loss	Dhawan et al. (2007)
Papaya mealybug, *Paracoccus marginatus*	Papaya	Tamil Nadu, Karnataka, Maharashtra	Abnormal weather conditions Misuse of insecticides	Significant yield loss	Tanwar et al. (2010)

Climate change effects on expression of resistance to insect pests

Host plant resistance to insects is one of the most environmental friendly components of pest management. However, climate change may alter the interactions between the insect pests and their host plants (Sharma 2012b). Resistance to sorghum midge, observed in India, breaks down under high humidity and moderate temperatures in Kenya (Sharma et al. 1999). There will be increased impact on insect pests which benefit from reduced host defenses as a result of the stress caused by the lack of adaptation to sub-optimal climatic conditions. Problems with new insect pests will occur if climatic changes favor the introduction of non-resistant crops or cultivars. The introduction of new crops and cultivars to take advantage of the new environmental conditions is one of the adaptive methods suggested as a possible response to climate change (Parry and Carter 1989).

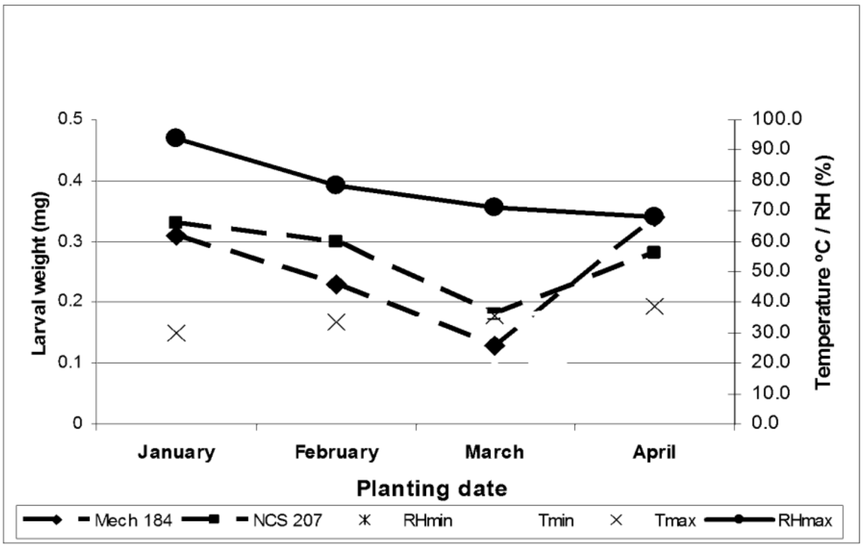

Fig 3. Effect of climatic factors on expression of resistance (larval weight) in *Bt* transgenic cotton to bollworm, *Helicoverpa armigera* (Sharma 2013).

Insect - host plant interactions will change in response to the effects of CO_2 on nutritional quality and secondary metabolites of the host plants. Increased levels of CO_2 will enhance plant growth, but may also increase the damage caused by some phytophagous insects (Coviella and Trumble 1999). The effects of increased atmospheric CO_2 on herbivory will not only be species-specific, but also specific to each insect-plant system. Increased CO_2 may also cause a slight decrease in nitrogen-based defenses (e.g., alkaloids) and a slight increase in carbon-based defenses (e.g., tannins). Lower foliar nitrogen due to CO_2 causes an increase in food consumption by the herbivores up to 40%, while unusually severe drought increases the damage by insect species such as spotted stem borer, *Chilo partellus* (Swin.) in sorghum (Sharma et al., 2005).

Environmental factors such as soil moisture, soil fertility, and temperature have strong influence on the expression of *Bt* toxins in transgenic plants (Sachs et al. 1998; Sharma 2013) (Fig. 3). Cotton bollworm, *Heliothis virescens* (F.) destroyed *Bt* cottons due to high temperatures in Texas, USA (Kaiser 1996). Similarly*, H. armigera* destroyed the cotton crop in the second half of the growing season in Australia because of reduced production of *Bt* toxins in the transgenic crops. Possible causes for the failure of insect control may be: inadequate production of the toxin protein, 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.

Climate change effects on 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 (Table 5). Changes in temperature will also alter the timing of diurnal activity patterns of different groups of insects, and changes in interspecific interactions could also alter the effectiveness of natural enemies for pest management (Hill and Dymock 1989). Quantifying the effect of climate change on the activity and effectiveness of natural enemies will be a major concern in future pest management programs. The majority of insects are benign to agro-ecosystems, and there is much evidence to suggest that it is due to population control through interspecific interactions among insect pests and their natural enemies (pathogens, parasites, and predators). Oriental armyworm, *Mythimna separata* (Walk.) populations increase during extended periods of drought (which is detrimental to the natural enemies), followed by heavy rainfall (Sharma et al., 2002). Aphid abundance increases with an increase in CO_2 and temperature, however, the parasitism rates remain unchanged in elevated CO_2. Temperature not only affects the rate of insect development, but also has a profound effect on fecundity and sex ratio of parasitoids (Dhillon and Sharma 2009). 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 5. Climate change effects on insect pest - natural enemy interactions.

Climatic variability	Crop	Insect pest	Natural enemy	Stage of insect	Potential impact
Decreased rainfall in Sept and Oct	Sorghum	Stem borer, *Chilo partellus* (Swin.)	*Trichogramma chilonis* Ishii	Eggs	Increase
Increased rainfall variability	Castor	Semilooper, *Achaea janata* Lin.	*Trichogramma chilonis* Ishii	Eggs	Decrease
Decrease in rainfall in Jun-Sept	Soybean	Leaf eating caterpillar, *Spodoptera litura* (Fab.)	*Telenomus remus* (Nixon) *Cotesia flavipes* (Cam.)	Eggs Larvae	Decrease Decrease
Increase in rainfall events	Groundnut	Leafminer, *Aproaerema modicella* (Dev.)	*T. chilonis* *T. remus*	Eggs	Decrease
		S. litura	*C. flavipes*	Larvae	30-40% decrease
Dry weather conditions	Chickpea, pigeonpea	Pod borer, *Helicoverpa armigera* (Hub.)	*Campoletis chloridae* Uchida	Larvae	Decrease
Decrease in August rainfall	Rice	Yellow stem borer, *Scripophaga incertulas* (Walk.)	*Tetrastichus* spp.	Eggs	Up to 100% increase

Rao et al., (2010).

Climate change effects on efficacy of bio-pesticides 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 (Sharma 2012a). Natural plant products, entomopathogenic viruses, fungi, bacteria, and nematodes, and synthetic pesticides are highly sensitive to the environment. Increase in temperatures and UV radiation, and a decrease in relative humidity may render many of these control tactics to be less effective, and such an effect will be more pronounced on natural plant products and the biopesticides. Therefore, there is a need to develop appropriate strategies for pest management that will be effective under situations of global warming in future. Farmers will need a set of pest control strategies that can produce sustainable yields under climatic change.

The relationship between the inputs costs and the resulting benefits will change as a result of changes in insect-plant interactions. 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. Increased temperatures and UV radiation, and low relative humidity may render many of these control tactics to be less effective, and therefore, there is a need to address these issues on an urgent basis for sustainable crop production and food security.

Strategies to mitigate the effects of climate change

Cultural practices, natural enemies, host plant resistance, biopesticides, and synthetic pesticides are now being widely used for pest management. However, many of these methods of pest control are highly sensitive to the environment. Therefore, there is a need to develop appropriate strategies for pest management that will be effective under situations of global warming in future.

- Host plant resistance to insects is one of the most environmental friendly components of pest management. It is important to identify and develop cultivars that are stable in expression of resistance to the target pests under variable climate.
- Transgenic crops have been developed for controlling some of the most intractable pest problems. There is need to combine host plant resistance from the germplasm with the transgene expression that is stable across environments, and locations.
- Crop diversification is one of the most effective methods of increasing the activity an abundance of natural enemies. There is need to develop crop cultivars that are hospitable to the natural enemies, in addition to identifying cropping systems that will enhance the diversity of natural enemies for pest management.
- There is a need for a greater understanding of the effect of climate change on the efficacy of synthetic insecticides, their persistence in the environment. Therefore, there is need to develop pesticide formulations and the application schedules that will be least affected by climate change.

Finally, we need to use an integrated pest management system that takes into consideration the change in pest spectrum, cropping patterns and effectiveness of different components of pest management for sustainable crop production.

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